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U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

TREC TECHNICAL REPORT 61-45

SMALL ROCKET LIFT DEVICE
PHASE I
DESIGN, FABRICATION AND STATIC TESTING

Task 9R38-11-009-14

Contract DA 44-177-TC-642

MARCH
~~April~~ 1961

Prepared by:

BELL AEROSYSTEMS COMPANY
Buffalo, New York

FOR OFFICIAL USE ONLY

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SMALL ROCKET LIFT DEVICE – PHASE I

DESIGN, FABRICATION, AND STATIC TESTING

15 August 1960 to 23 December 1960

Wendell F. Moore

Wendell F. Moore
SRLD Technical Director

Prepared by:

BELL AEROSYSTEMS COMPANY
Buffalo, New York

for

U. S. ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

FOREWORD

The prosecution of a research and development program involving the direct application of rocket power to man, thus permitting him a limited range of flight, requires the dedicated efforts of many specialists. Through the generous contribution of knowledge, advice, and time of such men, the SRLD Phase I program has been remarkably successful.

The USATRECOM has assigned Mr. Robert Graham as Project Officer; his understanding help and advice have been of great value. Mr. Wendell Moore serves as Technical Director for Bell Aerosystems Company. Acknowledgement is made of the excellent analyses by Messers C. Henderson and J. Kroll of Stability and Control, Mr. S. Czarnecki of Reliability aspects, Mr. M. Drexhage for the excellent gas generator design, and Mr. E. Ganczak for his overall system design efforts which have been a large factor in producing results on schedule.

Phase I of the SRLD program was initiated on 10 August, 1960, and was completed on schedule 23 December, 1960.

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ILLUSTRATIONS

TABLES

LIST OF SYMBOLS

Symbol	Unit	
b_3	lb/ft/sec	artificial damping applied to stabilizer-mass
b_N	ft-lb/rad/sec	damping of control nozzle
BT	°F	insulation barrier temperature (cold side, left ring attachment)
C*	ft/sec	characteristic exhaust velocity
d_3	ft	distance from stabilizer mass to nozzle gimbal
EXT	°F	exhaust temperature (3 feet from nozzle)
F	lb	thrust
F_{corr}	lb	thrust (corrected to 410 psig feed line pressure)
FLP	psig	feed line pressure
FLT	°F	feed line temperature
GGP	psig	gas generator pressure (corrected to 410 psig feed line pressure)
GGT	°F	gas generator temperature
I_N	slug-ft^2	moment of inertia of nozzle about gimbal axis
I_{sp}	sec	specific impulse
I_1	slug-ft^2	moment of inertia of upper torso about hip socket

Symbol	Unit	
RNP	psig	right nozzle pressure
RNT	°F	right nozzle temperature
TP	psig	tank pressure
T_R	lb	total thrust
T_{s_1}	°F	tube skin temperature (6 inch from gas generator)
T_{s_2}	°F	tube skin temperature (at tube bend)
T_{s_3}	°F	tube skin temperature (3 inch from nozzle)
W	lb/sec	weight flow
W_{corr}	lb/sec	weight flow (corrected to 410 psig feed line pressure)
W_s	rad/sec	natural frequency of stability augmentation
X	ft	lateral displacement
g	ft/sec^2	gravitational acceleration
x	inches	display lateral displacement
δ_p	psi	differential pressure
δ_c	degree	manual control deflection
δ_s	degree	stability augmentation system control deflection
ζ	$ft\text{-}lb/rad^2/sec^2$	damping ratio of stability augmentation system
ω_n	rad/sec	undamped natural frequency of stability augmentation system

Symbol	Unit	
I_2	slug-ft^2	moment of inertia or lower torso about hip socket
K_1	ft-lb/rad	hip spring constant
K_N	ft-lb/rad	stiffness of control nozzle
K_8	lb/ft	spring constant of stabilizer spring
LNP	psig	left nozzle pressure
LNT	°F	left nozzle temperature
LP	psig	line pressure
M	ft-lb.	rolling moment
l_1	ft	distance from nozzle gimbal axis to upper torso center of gravity
l_2	ft	distance from upper torso center of gravity to hip socket
l_3	ft	distance from lower torso center of gravity to hip socket
l_5	ft	distance from body centerline to stabilizer mass
m_1	slugs	mass of upper torso
m_2	slugs	mass of lower torso
m_3	slugs	stabilizer mass
P_cAbs Corr		chamber pressure (corrected to absolute)
PFT	°F	propellant feed temperature
q_1	degree	roll angle of upper torso (above hip socket)

LIST OF SYMBOLS (CONT)

Symbol	Unit	
q_2	degree	roll angle of lower torso (below hip socket)
δ_n	degree	nozzle deflection
θ	degree	stick deflection

SUMMARY

In answer to a generalized requirement for increased mobility of the foot solider, an approach has been conceived wherein small rocket units are attached directly to an individual to provide him a short flight capability. An analytical study of the feasibility of such a system has revealed that such a device can be built with characteristics of reliability, stability, and controllability, and one which would be safe for operation by relatively inexperienced personnel.

To substantiate the theoretical investigations and captive flight tests utilizing nitrogen gas, it was deemed necessary to build a manned free-flight feasibility model of such a device and flight test it. Toward this end, Bell Aerosystems Company was awarded Contract No. DA-44-177-TC-642 to perform this task under the direction of the U.S. Army Transportation Research Command (TRECOM), Fort Eustis, Virginia.

The Contract Work Statement for this task was divided in two distinct phases. Phase I requires the design, fabrication, component testing and assembly of the Small Rocket Lift Device, followed by an engineering report of this work. Phase II requires static test firings of the assembled unit, tethered and free-flight testing with a human operator to determine the overall feasibility, performance, safety and utility of such a device, with adjustments and modifications as required to achieve satisfactory operation. A Phase II engineering report is to be issued along with a documentary movie of the flight test program.

The general approach to the design of the SRLD is to mount a hydrogen peroxide rocket propulsion system on a molded Fiberglas corset, shaped to fit the body of the operator. Underarm lift rings are attached to the corset through a central, laterally-pivoted joint at the back of the operator's neck. Two handles attached to the rings extend forward for control purposes. Actual lift is provided by two gimballed rocket nozzles, one mounted on each side of the operator outboard of the arms and above the center of gravity. The nozzles are fed by a central gas generator controlled by a squeeze throttle at the operator's right hand.

Flight stability and control of this feasibility model can be achieved by any combination of three methods; namely,

1. Pure kinesthetic control by body motions.

2. Roll damping only by automatic outward lateral gimballing of the nozzles when excited by lateral rotational accelerations.

3. A control stick mounted on the left forward arm which operates the gimballed nozzles for pitch, roll, and yaw.

Figure 1 is a photo of the actual SRLD.

During this Phase I period, all propulsion system components were designed, procured and tested on schedule. No major difficulties were encountered. Nozzle positions and control deflections were determined during a stability and control analysis with the aid of a "REAC" analog computor. Reliability aspects of the SRLD were compiled and determined as required. Human factors efforts during this period consisted of determining operator's body-mass data, flight control analysis and preparation of a tethered-flight test plan.

As a result of the successful component developments and system tests it was concluded that the system design was both safe and reliable enough to proceed with manned tethered and free-flight testing of the SRLD.

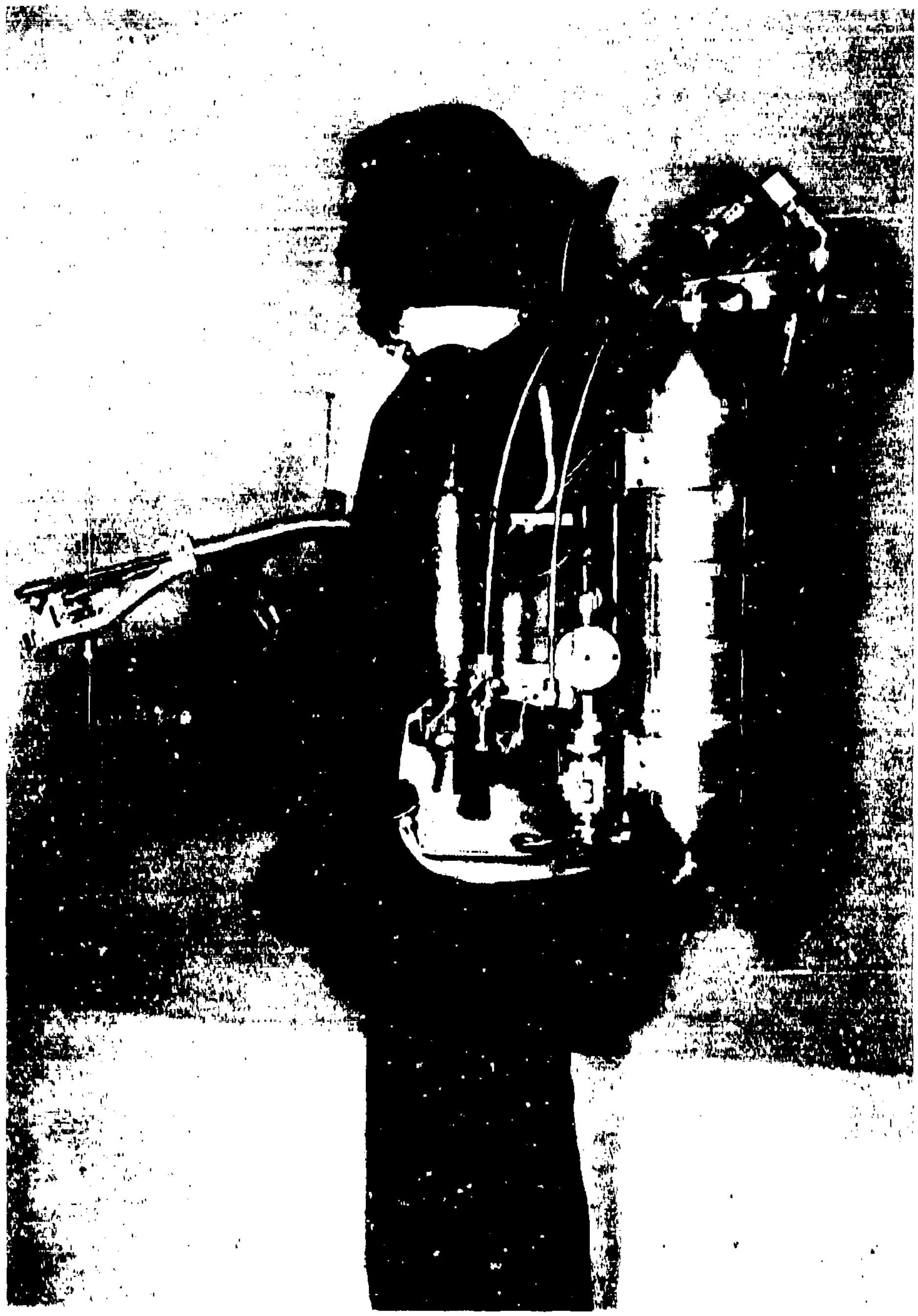


Figure 1. Small Rocket Lift Device - Left Side View

CONCLUSIONS

The results of component design and testing as well as cold-flow system testing as reported herein indicate that the SRLD system as developed to date, will satisfy the requirements of safety and reliability necessary for manned flight tests.

RECOMMENDATIONS

It is recommended that Phase II of the program involving hot firing of the SRLD system and manned tethered and free-flight tests proceed immediately, utilizing the system as developed to date.

I. SYSTEM DESIGN

The fundamental purpose of designing and testing an SRLD as set forth in the contractual Statement of Work is to determine the feasibility of attaching a controlled rocket system to a man for the purpose of transporting him over relatively short distances. No particular effort was to be expended to optimize the system; therefore, proven components were used wherever possible. Toward this end, Bell Aerosystems has designed and constructed such a device under the direction of U.S. Army, TRECOM.

Some of the fundamental problems facing the designer of such a device are: The rocket thrust must be manually throttled from zero to one hundred per cent to provide adequate altitude control. The operator must carry sufficient propellant to provide something in the order of 30 seconds of thrust time, and to prove the feasibility of various maneuvers. Further, controls must be provided to direct the thrust of the individual nozzles as required, to transport the operator to his desired target.

Safety factors must be considered very carefully. Things to be considered here are the effects of high-temperature exhaust steam in close proximity to the operator's body, the range of controllability, and due to the short lift time that is practical in such a device, a propellant warning system must be incorporated. Another consideration involving safety is that of distributing the heavy load of the SRLD properly about the operator's body.

After taking some of the foregoing considerations into account it was decided as a result of study at Bell, and elsewhere, to design the SRLD body harness in the form of a corset. In order to be certain that this corset actually fit the operator and distributed the load properly, a plaster cast was made of the operator's body, and from this a male model of the plaster cast was made. The male model was built up one inch larger than the operator's actual body shape to allow for one inch thick padding to distribute the load evenly around the waist and buttocks. After completion of the plaster mold, the corset itself was laid upon it, utilizing Fiberglas cloth impregnated with epoxy resin. This was then cured overnight at room temperature. The steps depicting the fabrication of this Fiberglas corset are shown in Figures 2 and 3.

Figure 2. Plaster Molding Operation

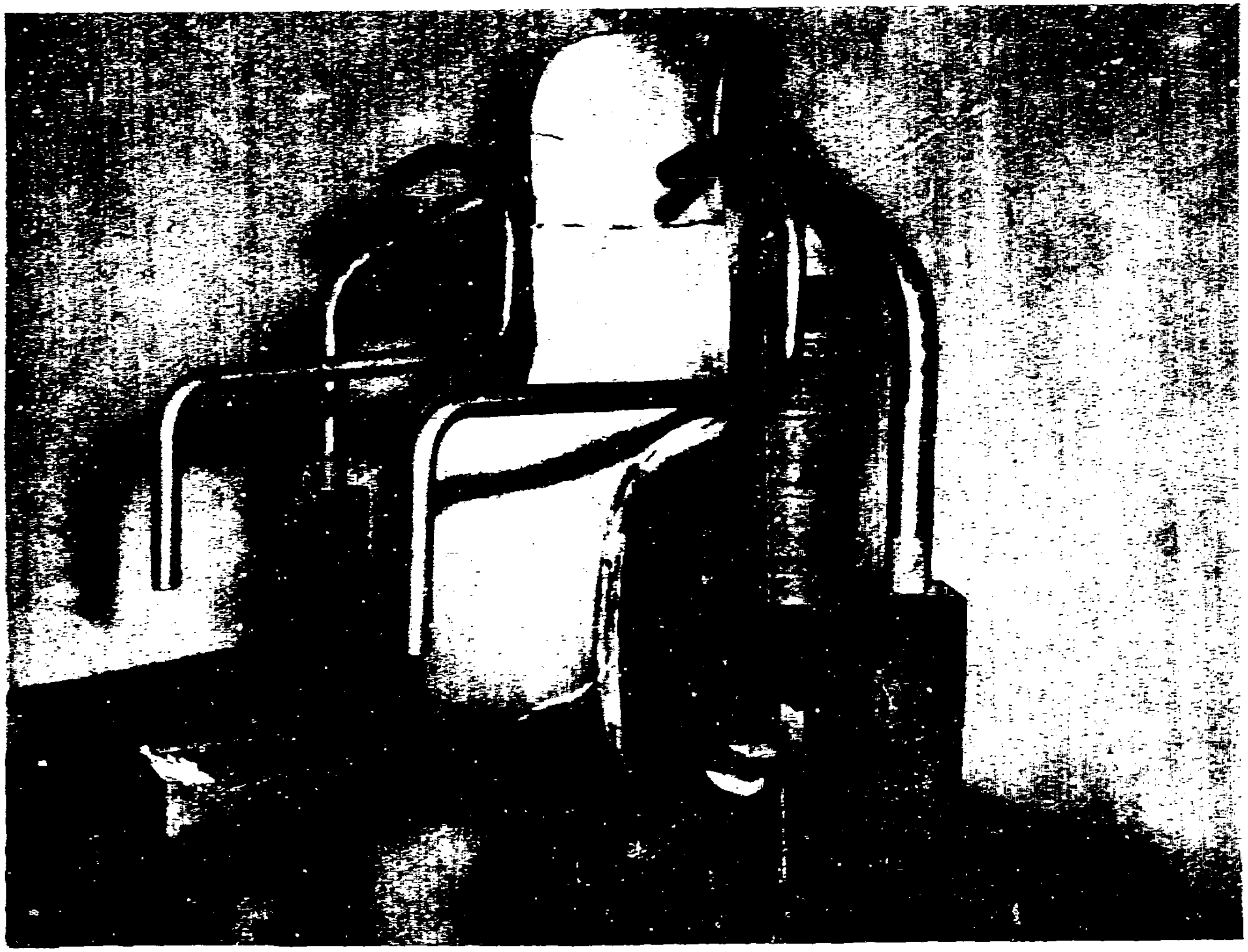


Figure 3. Three-Quarter Front View of Mockup

Careful consideration had to be given to the selection of the padding which lined this Fiberglas corset. Numerous materials were investigated. Among them being Dow Corning "Ethafoam", U. S. Rubber "Ensolite", and "Rubatex" manufactured by the Rubatex Division of Great American Industries Inc. Ethafoam is a foamed cellular Polyethylene material. The latter two are foamed polyvinyl chloride materials. All of the materials were evaluated for firmness, impact sensitivity, and bulk density. They were all immersed for at least 12 hours in 90 percent hydrogen peroxide to determine what, if any, reaction took place. The test data on these materials is presented in one of the preliminary test reports in Appendix I. Dow "Ethafoam" was selected for the padding of the SRLD corset for two fundamental reasons:

1. No chemical reaction occured during immersion for 24 hours in 90 percent peroxide.

2. The extremely low density of two pounds per cubic foot made it a desirable material for this application.

Another fundamental design consideration was how to lift the human operator. It was decided to use underarm lift rings as a result of past experience in experimenting with a nitrogen-powered rocket belt.

These rings were provided with control arms extending forward from the bottoms with hand control grips at each end. Underarm lifting admittedly is not the most comfortable method of lifting a human being; however, due to the short flight time of such a device, this was a very convenient and compact method of achieving this end. Further, it allows freedom of the operator's arms, shoulders, torso, and legs for kinesthetic control purposes. These lift rings were also padded with one inch thick "Ethafoam" tubing over the one inch diameter rings.

The hydrogen peroxide-powered propulsion system was then designed as a complete package in itself and mounted on a lightweight frame which in turn was bolted to the back of the Fiberglas corset at three points. The gas generator was attached to the top of this frame at about the level of the operator's neck by means of a radial pivot bearing. The purpose of the bearing is to allow the operator to shake or maneuver his shoulders laterally for lateral stability and control purposes. A flexible line is provided from the propellant tanks outlet to this moveable gas generator and throttle valve assembly. Two insulated outlet tubes were attached to the bottom of the gas generator to supply the two nozzles which were placed on each side of the operator, approximately 15 inches outboard of the

operator's center line. These nozzles were designed with integral gimbals and high-temperature seals in order to permit thrust vector control during flight.

Three distinct methods of control of the SRLD are provided for experimental purposes, namely:

1. Pure kinesthetic control by body motions.

2. Roll damping only by automatic outward gimballing of the nozzles, when excited by lateral rotational accelerations.

3. A control stick mounted on the left forward arm which operates the gimballed nozzles for pitch, roll and yaw.

The control stick is suspended in a vertical position at the end of the left arm extension by means of a spherical bearing. A mechanism was devised which permits roll, pitch and yaw control through a single hand grip. Control motions are transmitted to the gimballed nozzles through flexible push-pull controls. The maximum stick deflection is 15 degrees from center. No artificial feel or centering is provided at the present time.

The center of gravity relationships to the nozzle positions were designed according to the recommendations resulting from the stability and control analysis described elsewhere in this report. Figure 4 is a graphical illustration of this relationship.

The nozzle maximum deflection for full stick deflection was designed to be adjustable so that full maximum nozzle deflections of 3, 6, or 9 degrees could be explored during the flight test operations.

The automatic stability augmentation device was designed to actuate the nozzles about the gimbal when lateral rotational accelerations are experienced by the pilot during flight. A lateral acceleration toward the left would automatically flip the left nozzle outward tending to stabilize the system. The nozzles are blocked at the gimbals from turning inward toward the operator's body. Provision was made to lock both the stick and the nozzles in the neutral position for the purpose of exploring pure kinesthetic flight control.

The circular lift rings around the shoulders are provided with hinged sections at the front. These are lifted upward and snapped into place by

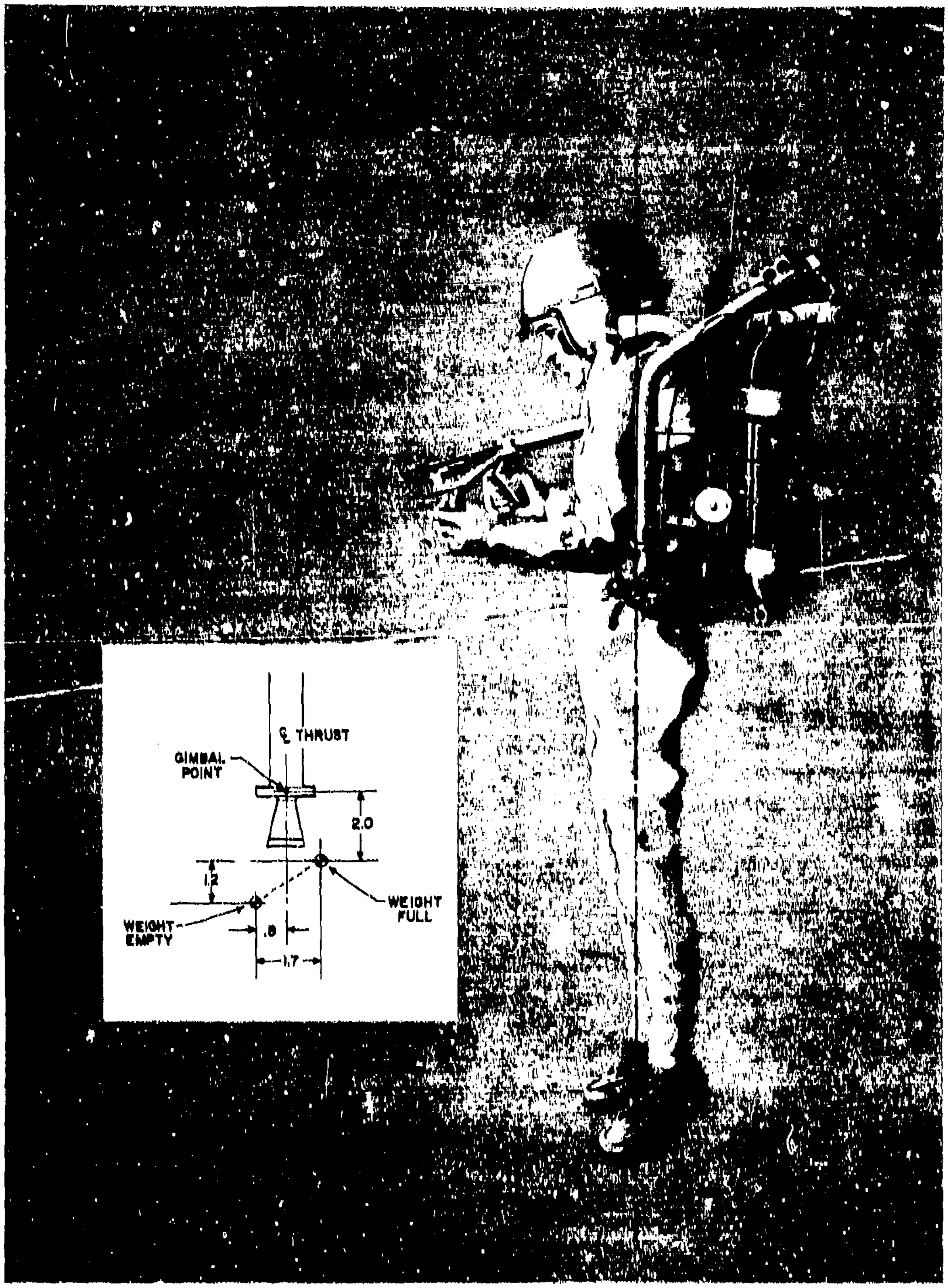


Figure 4. Man-Machine C.G. Relationship

means of specially-designed quick release fittings. A quick-release safety belt was procurred and installed around the waist of the Fibreglas corset in such a manner that it would tighten about the operator's stomach. It was found during testing of the mock-up, that it was desirable to add a "belly plate" from a stiff, 1/8 inch thick rubber material to support the abdomen while the operator was being lifted by the SRLD. Entrance to the SRLD is a matter of backing into the corset, snapping the quick release links into position and tightening the safety belt. Several different designs of throttle control were considered during the design phase. The one chosen for the first trials was a squeeze-type hand throttle placed at the end of the right arm extension and formed to fit around the knuckles of the right hand with the palm grip at the aft side. Squeezing this throttle control applies thrust in a predetermined fashion controlled by the throttle valve from zero to maximum. Releasing the throttle grip reduces the thrust. A suitable return spring is provided to return the throttle valve and the grip to zero.

Since the maximum flight time of this particular feasibility model of the SRLD is in the order of 30 seconds, a flight time or propellant remaining warning system had to be provided to signify flight time remaining to the pilot. Many types of systems were considered. Obviously, the best and most accurate type would be one based upon actual measurement of the propellant remaining in the tanks. However, such a system becomes quite expensive and complicated and was determined unnecessary during this phase of the program. The system actually selected and used in this SRLD is one that is based on theoretical propellant consumption. Both auditory and visual signals are provided to the pilot at 10 seconds before propellant burnout. The device fundamentally consists of a cammed chronometric DC timing motor connected to an electronic audio signal generator and warning light switches. The signal generator provides a "beep-beep" type of tone at one second intervals beginning ten seconds before theoretical burnout. This tone is provided to the operator through a head set in the crash helmet. The cam-actuated switches cause a red light mounted on the helmet at about the bridge of the pilot's nose to flash concurrent with the auditory signal. During initial hot-firing tests of the gas generator and nozzle assembly, this unit was tested. It was found that any variation provided in the auditory signal, both frequency and gain, could not actually command the operator's attention. However, in every case the red light at the edge of the operator's peripheral vision did command his attention to take action. Therefore, even though this auditory device has been retained, we have concluded that it is of no value in this program, fundamentally, because of the high noise level of the SRLD itself.

A photograph of this propellant warning device is shown in Figure 5. A schematic diagram of this device is shown in Figure 6.

Preliminary noise level investigations were made during the gas generator test cell firings. During Run No. LD-22 (see Appendix IV) a meter located where the pilot's head would be read 131 decibels. A noise level of 133.5 decibels occurred when the meter was placed between the nozzle exits on Run No. LD-28.

Concern was evidenced by many people over the possibility of the pilot being burned about the legs and feet from the high-temperature steam of the rocket exhaust during operation. It was considered that the worst condition which could occur would be the heat generated during a full duration equivalent tiedown run. During the reliability testing program of the gas generator and nozzle assembly, thermocouples were placed beneath one of the nozzles at a distance equivalent to the ground level with the operator standing. One thermocouple was placed directly on the center vertical line of the nozzle, the second and third were placed 18 inches inboard and outboard of this center. The maximum temperature encounted during this test was 400°F. As a result of these tests it was determined that no particular harm would come to the operator provided he at least had a pair of heavy trousers and boots on. A schematic of this test set-up along with a small table indicating the maximum temperatures achieved is shown in Figure 7. In addition to the squeeze type throttle control it has been decided to test a motorcycle type of throttle control. A Harley-Davidson motorcycle control grip was therefore purchased and is being modified to actuate the push-pull control of the SRLD throttle. During the flight test program both throttles will be evaluated. The pertinent dimensions of both throttle control systems are given in Figure 8.

No particular effort was made during the design of this feasibility model to optimize the system so far as weight was concerned. For example, an existing ICC-approved high pressure nitrogen bottle was utilized for source gas in the propulsion system, and two existing Air Force breathing oxygen bottles were utilized for propellant tanks. As a result the SRLD empty weight as it stands today, in flight-ready condition, is 79.57 pounds. The operator's weight, ready for flight including suit and helmet, stands at 154.4 pounds. Forty-seven pounds of hydrogen peroxide are loaded in the propellant tanks and two pounds of nitrogen gas charged in the high pressure cylinder. Taking all the foregoing into account, the take-off weight of the SRLD is 283.97 pounds. Table 1 is a detailed weight breakdown of the SRLD system.

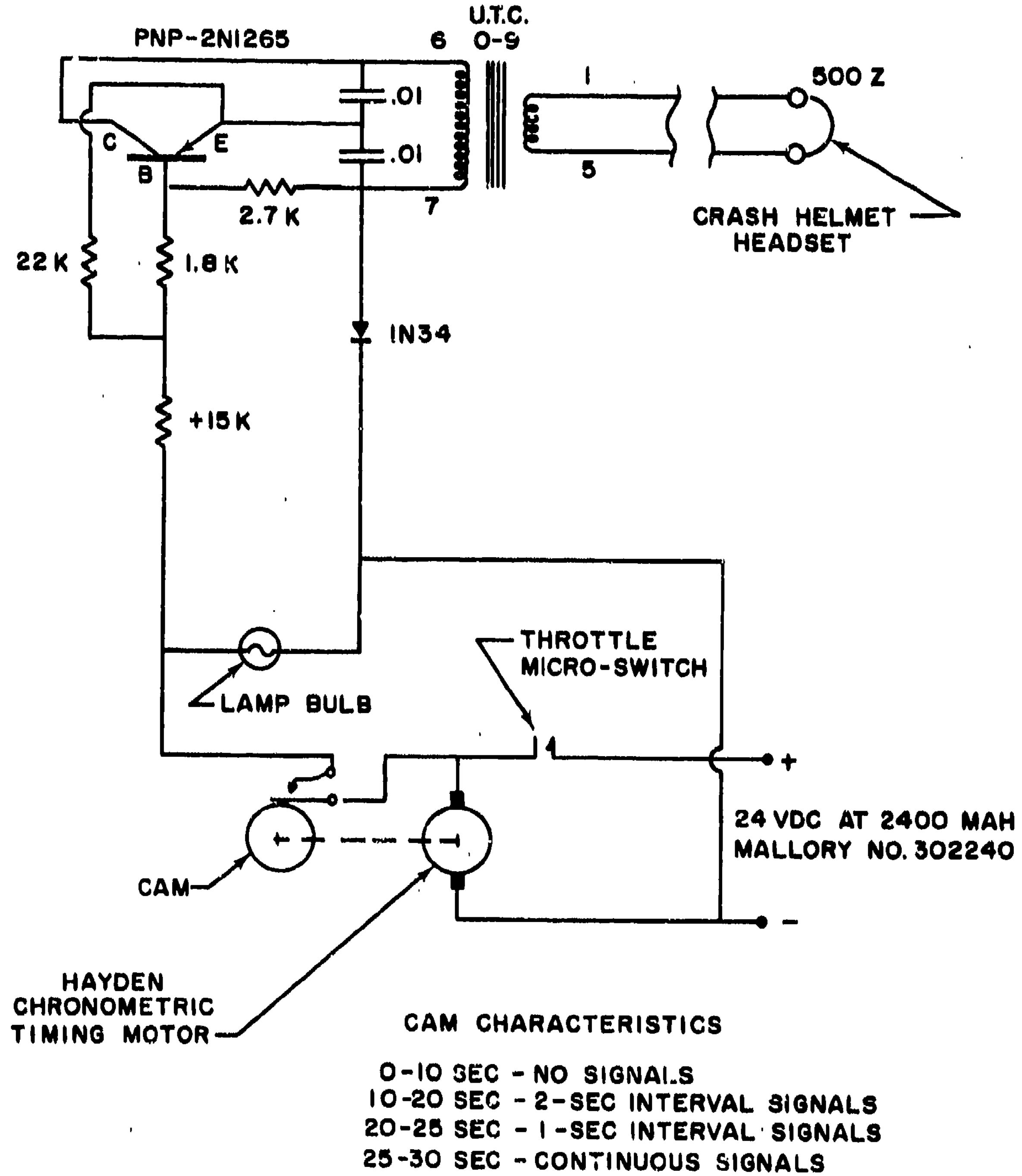


Figure 6. SRLD Propellant Timer — Schematic Diagram

THERMO. & LOCATION	MAX. TEMP.
$T_C F_1$	240°
$T_C F_2$	400°
$T_C F_3$	220°

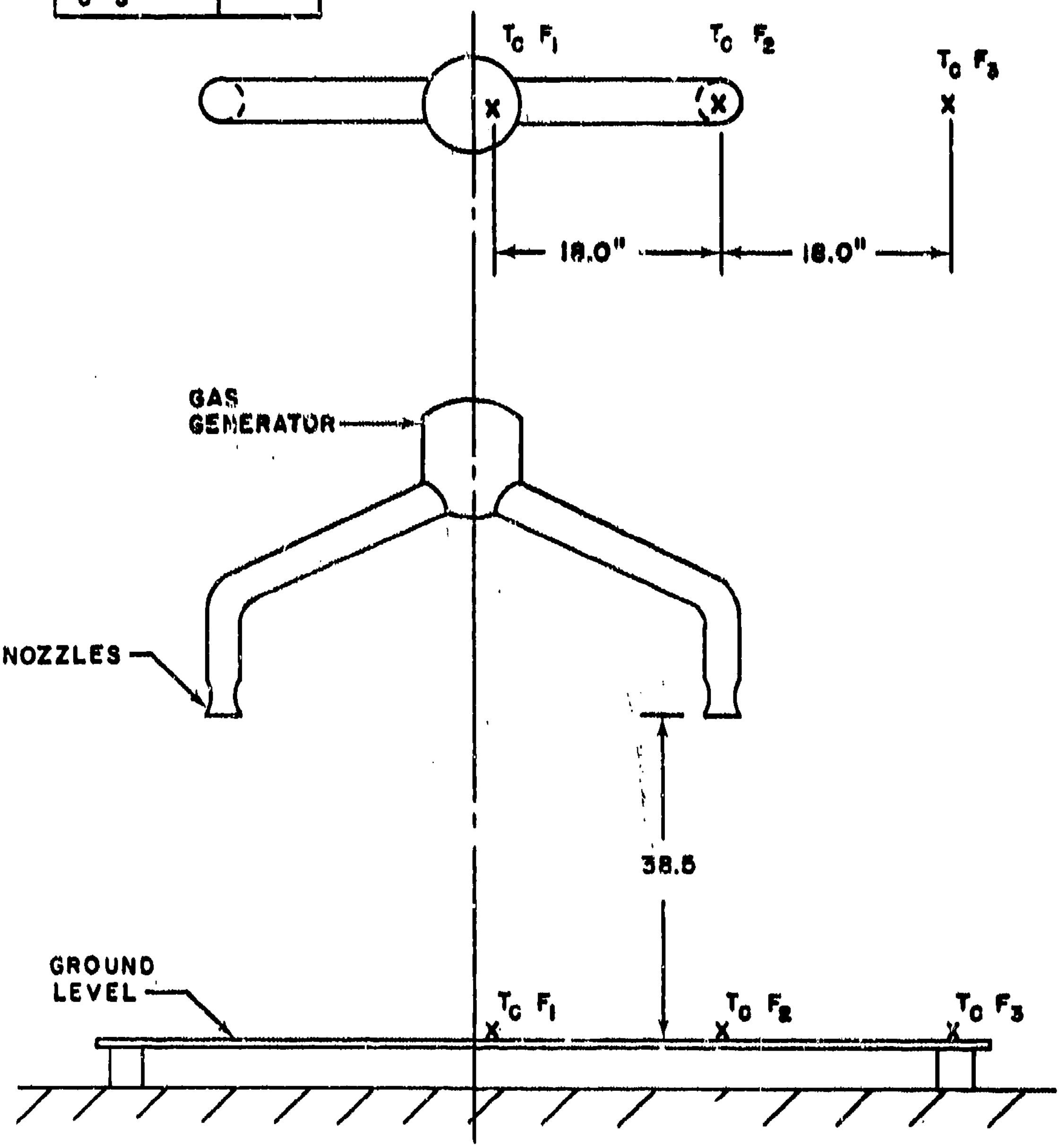


Figure 7. Exhaust Temperature Survey

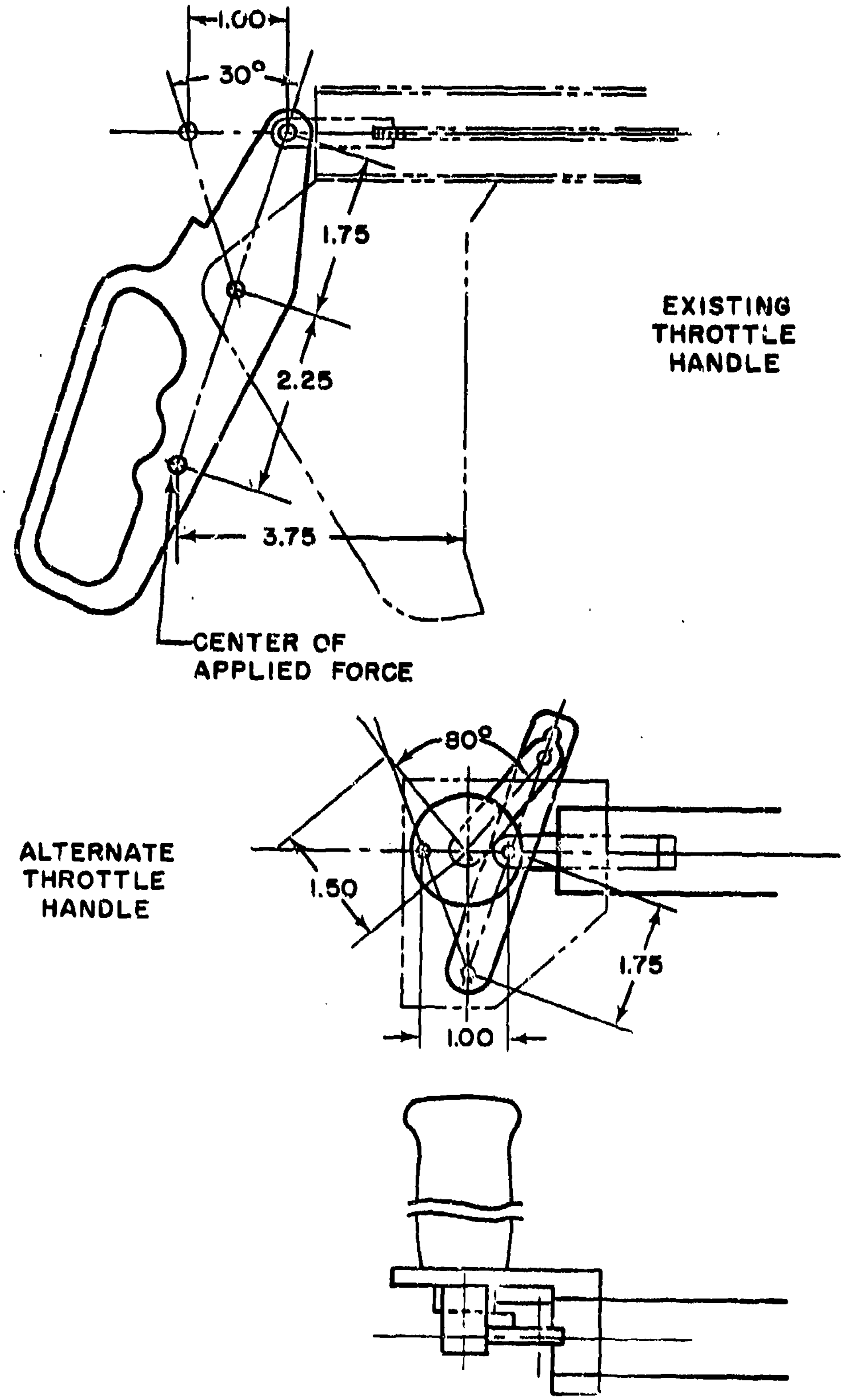


Figure 8. Throttle Control Designs

TABLE 1

SRLD WEIGHT BREAKDOWN

Item No.	Part No.	Part Name	Weight (pounds)
1	AN6025BX415-21	N_2 Storage Bottle	16.25
2	MS28889-1	Hi-Press Fill Valve	.16
3	2725-3	Hi-Press Gage	.15
4	8060-472001	Shutoff Valve	.54
5	8060-472004	Filter	.24
6	8123-472010	N_2 Regulator	1.65
7	8123-472003	Check Valve	.19
8	8123-472015	Press. & Vent Valve	.50
9	8060-472122	Relief Valve	.36
10	1525-316SS	Lo Press Gage	.30
11	8123-471001	Storage Tank Assy H_2O_2	12.25
12	8123-472005 (2)	Manual H_2O_2 Fill, Drain & Bleed Valve	.28
13	8123-472002	Throttle Valve	1.40
14	8123-470001	Gas Generator Assy	5.69
15	8123-470040 (2)	Gimballed Nozzle Assy	2.40
16	R22533-10-0180	Flexible Hose	.60
17	8123-460009	Harness & Insulation	5.50
18	8123-460008	Support Frame Assy	2.30
19	8123-460007	Lift Support Assy (Minus Gas Gen.)	10.80
20		Control Cables (Including Throttle)	5.25
21		Throttle Handle	.86
22		Control Stick Assy	1.65
23		Belt & Abdominal Support	1.25
24		Upper Tether Tiedown Support,	3.00
25		Battery & Timing Equipment	4.00
26		Plumbing & Miscellaneous Fittings	2.00
		SRLD Empty Weight =	79.57 lbs.
	Operator		141.00
	Flight Suit		4.50
	Insulated Underclothes		1.25
	Boots		4.40
	Helmet		3.25
		Operator's Weight =	154.40
		Propellant Weight =	47.00
		Source Press Weight =	2.00
		Takeoff Weight =	283.97 lbs.

A special flight suit was designed and fabricated for the SRLD operator. This was done primarily from the standpoint of safety and secondly of obtaining good engineering data on the body and limb positions. The suit was designed to be worn over quilted "dacron" underwear and was fabricated in such a fashion as to draw the material tightly about the limbs and torso, so that body joints, leg angles, etc, would be readily detectable on the flight films for analysis purposes. The suit itself was fabricated from chartreuse-colored "Graylite" material, a polyvinyl-impregnated cloth. This material is suitable for use with raw hydrogen peroxide. Nine-inch insulated boots with a deep ripple, soft-rubber sole were procurred for the operator's use. These will afford the maximum protection from accidental ankle injuries, hard landings, and high temperature exhaust. Figure 9 is a photo of this flight clothing as worn by the operator.

Figure 9. SRLD Flying Suit - Side View

II. PROPULSION SYSTEM

A simple pressurized 90% hydrogen peroxide propulsion system was chosen to power this feasibility model of the SRLD. Whenever possible, proven components were utilized to enhance the safety and reliability of the system. Referring to the photo-schematic (Figure 10), beginning at the bottom center is a standard high-pressure cylinder in which nitrogen gas is stored at 2100 psi. The bottle is charged through a standard aircraft-type hi-pressure fill valve and pressure is indicated to the operator by a miniature high pressure gauge. The stored gas flow into the system is controlled by a manually-operated N_2 shutoff valve developed for the Mercury Project. This is followed by a high-pressure, 10-micron filter also developed for H_2O_2 systems on the Mercury Project. The filter flows into a Bell-modified Grove "Mitey-Mite" pressure regulator. The regulator is a normally-open, gas-loaded dome type. A suitable check valve is provided at the outlet of the pressure regulator and eliminates any possible back-flow of H_2O_2 in the event of accidental source gas loss after propellant tank pressurization. Pressure to and from the propellant tankage assembly is manually controlled, by means of a "pressurize and vent" (3-way) valve. A 0-600 psi. peroxide-compatible tank pressure gauge is teed into the tank pressurization line just downstream of the "Press. & Vent" valve along with a tank pressure relief valve, set at 525 psi. The latter two valves are also Mercury components.

The propellant tankage system consists of two modified AF type D-2 breathing oxygen bottles tied together at the bottom by special bosses and a manifold. Located at one end of the manifold is a small shutoff valve. This valve is used to fill and drain the tankage system. Inserted in the top of each tank is a tube that is connected to another shutoff valve. This is the tank bleed valve. These overflow tubes are inserted at a predetermined height to control the amount of ullage when the tank is filled. The propellant flows under a pressure of 450 psi from the center of the manifold through a flexible line to the throttle valve.

The throttle valve is a plunger and spool type valve. The spool has a series of orifices which when uncovered by the plunger varies the amount of hydrogen peroxide flow from zero to maximum flow to the gas generator. Peroxide flowing from the throttle valve is decomposed by catalytic action in the gas generator. The decomposed gases are directed through and expanded in the two exhaust nozzles to produce thrust proportional to the peroxide flow.

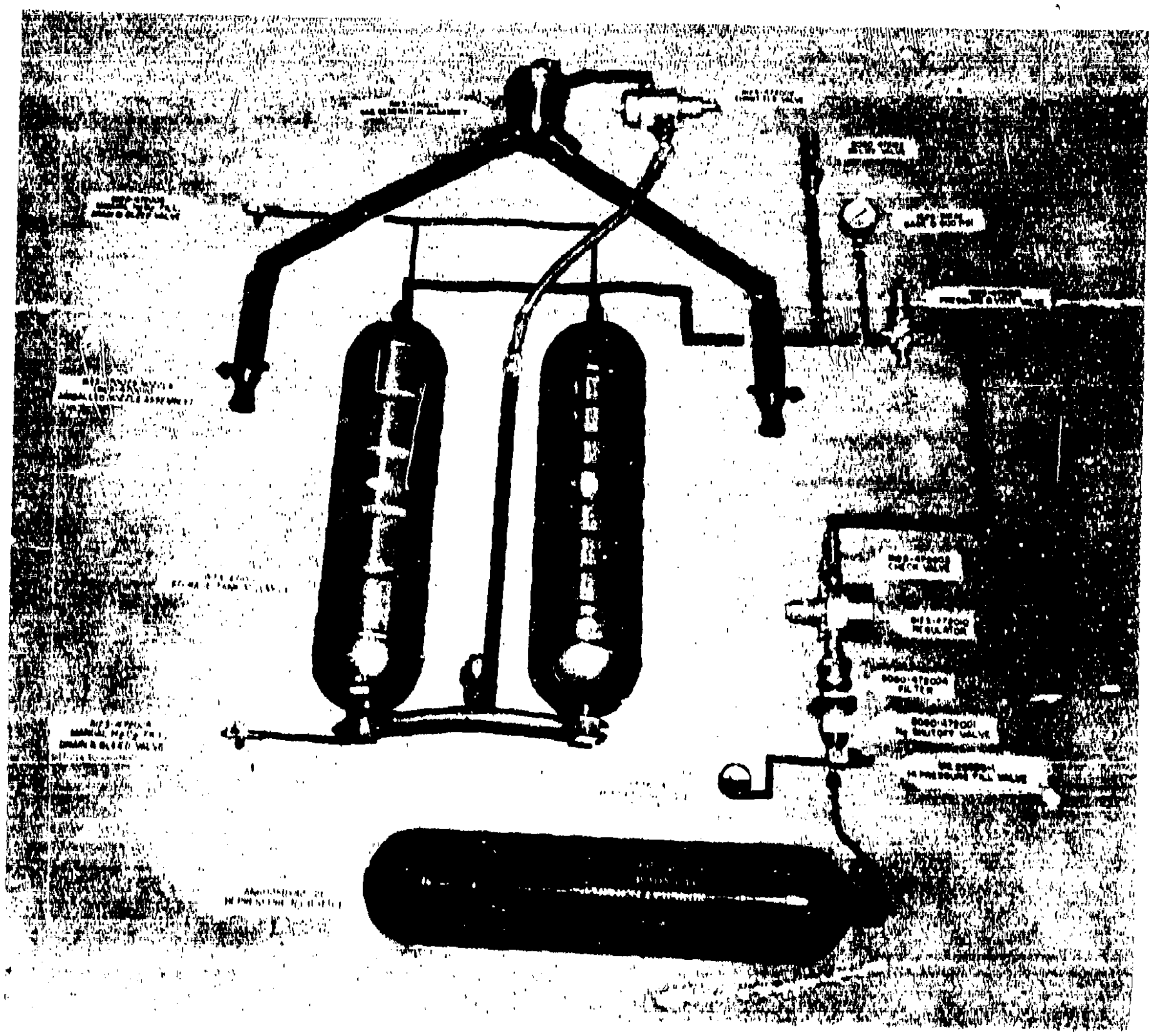


Figure 10. System Components - Photo Schematic

The two exhaust nozzles are gimballed and are controllable for pitch, yaw, and roll by movement of the left hand grip if desired.

To actuate the propulsion system, the operator places the P and V valve in "Pressurize" posistion, opens the N_2 shutoff valve, and squeezes the throttle control.

After the initial build-up of the propulsion system was completed, it was chemically cleaned and filled with distilled water for test purposes. The actual pressurization and flow tests with distilled water were successfully completed without incident. Residual propellant, (water in this case) averages approximately 2 pounds when the first gas bubble goes through the gas generator feed line. The nitrogen supply pressure averaged about 900 psi at the end of liquid expulsion when the initial charge was 2100 psi. The modified Grove regulator pressure drop-off was within the expected values. Various types of pressurization and flow rate changes were tried. The purpose of these tests was to detect any possible malfunction tendencies of the system or components. No problems were encountered. The detailed test data for these water flow test reports are shown in Appendix II.

The completion of the foregoing system water flow test represented the final work requirement in Phase I of this contract. Phase II was begun with hot-captive firings in the test cell with a weighted plaster dummy. This will be followed by manned captive flight tests and finally manned free-flight tests.

SRLD PERFORMANCE SUMMARY

Thrust	280 lbs. nominal
Throttle Range	0 to 100%
I_{sp} (100% Thrust)	120^+ min.
Propellant (H_2O_2)	47 lbs. max.
N_2 Source Pressure	2100 psi
Tank Pressure	450 psi
Relief Valve Pressure	525 psi
Nominal Duration	$\approx$ 22 sec.

The following itemized list gives all the basic information and test results of the individual components that are used in the propulsion system.

AN6025BX415-21 Nitrogen Storage Bottles

Certified material and test information were received from the vendor (Walter Kidde Company). The bottles were hydrostatically tested to 3500 psi. Permanent expansion was 0.2 cubic centimeters on one bottle and 0.5 cubic centimeters on the second bottle. One unit is mounted on the SRLD and the other is being held for a spare.

MS28889-1 High Pressure Charging Valve

This government standard part is satisfactory for service operation at 3000 psi, is fully developed, and is available from government-approved sources which are on the QPL list. Two of these units were cleaned and functionally tested. One item was installed on the SRLD and the other is being held for a spare.

2725-3 High Pressure Gauge 0-3000 psi

Two small gauges (0-3000 psi) were purchased from Rochester Manufacturing Company. These gauges were not compatible with hydrogen peroxide. However, due to the fact that they are used in the source gas system, they are considered acceptable. The gauges were processed chemically clean at Bell Aerosystems Company. Calibration curves of these gauges are presented in Figure 11.

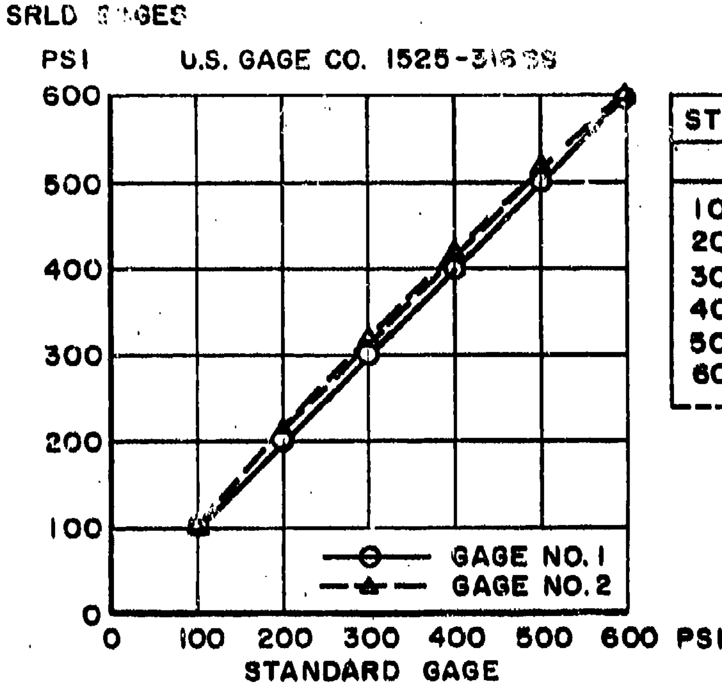
8060-472001 Manual Nitrogen Shutoff Valve

This valve is a manually-operated ball-type valve which has been developed for use in H_2O_2 pressurizing gas systems. The operating range is 0 to 3000 psi., requires a rotary motion of 90 degrees, and approximately 12 inch-pounds of torque. Leakage external and internal does not exceed 5 cc per hour and life is 1000 cycles.

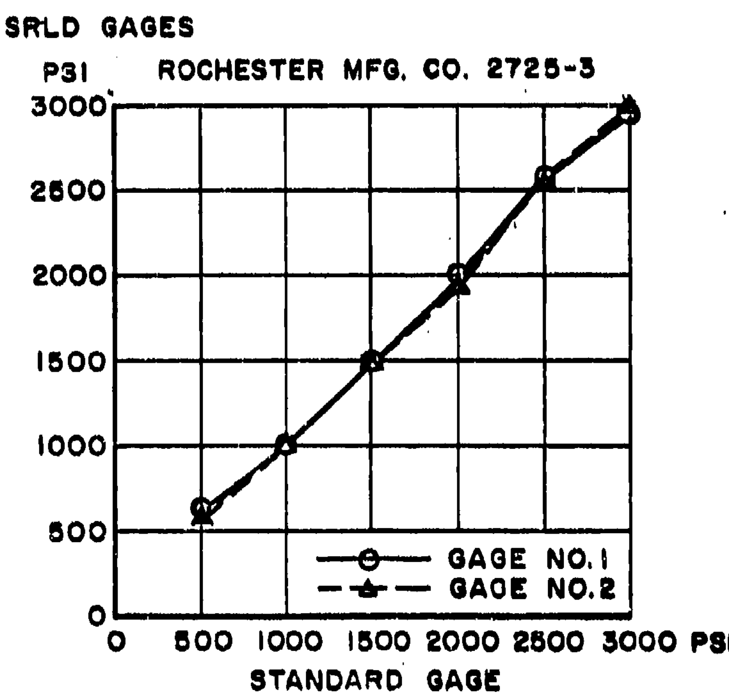
Accountability of two of these units was transferred from the "Mercury" program to the SRLD program and to be used in the "as is" condition. Another unit was bought specifically for the SRLD program and is available for use. Pressure drop and flow data are shown in Figure 12.

8060-472004 Filter

This is a 10 micron, 304 stainless steel, convoluted wire mesh filter encased with an aluminum body developed for the Mercury Project. The operating pressure range is 0-3000 psi. Cycle life without structural failure is 2000 cycles with pressure applied from 0 to 3000 psi.



STD	NO. 1		NO. 2	
	UP	DN	UP	DN
100	100	100	100	100
200	201	201	209	205
300	301	301	310	310
400	401	401	415	419
500	501	501	519	521
600	602	602	600	600



STD	NO. 1	NO. 2
500	600	580
1000	1000	1000
1500	1480	1480
2000	1980	1960
2500	2580	2580
3000	2950	2980

Figure 11. Calibration Curves of the SRLD Pressure Gauges

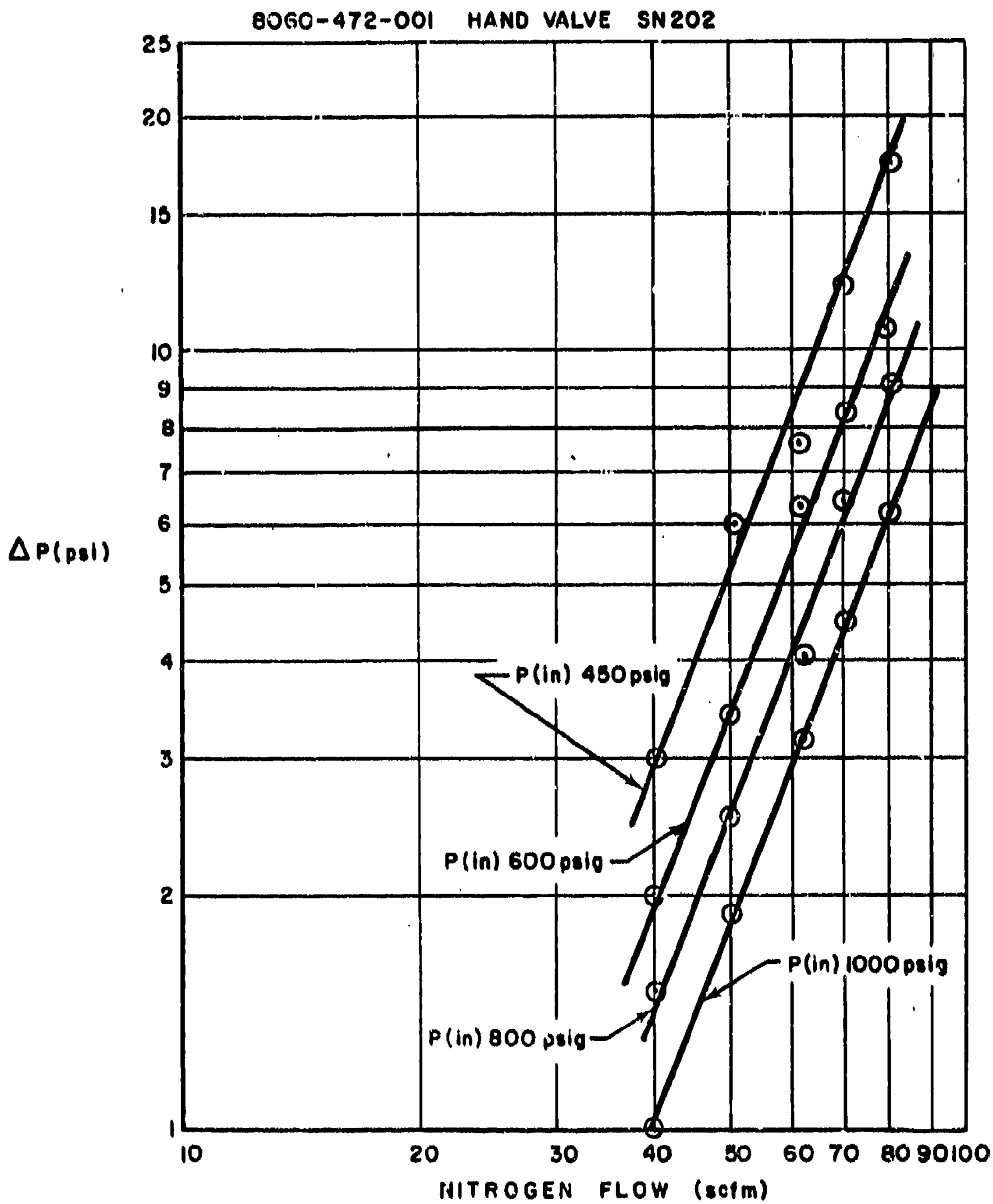


Figure 12. Gas Flow vs ΔP (Hand Valve)

Two of these filters were transferred from the "Mercury" program to the SRLD program, to be used in the "as is" condition. An additional unit has been purchased and is now available. Figure 13 shows the gas flow test results at various inlet pressures versus pressure drops.

8123-472010 Pressure Regulator

Unless an extensive development program was authorized, Scott Aviation would not supply components for modification to meet the SRLD requirements. Consequently, an "off the shelf" Grove Regulator Company, Model 94X "Mitey-Mite" regulator was selected. Initial informal tests indicated that a balanced poppet design was required to reduce the regulated pressure drop during flow.

Two of these units were modified by Bell to incorporate this feature. See Appendix III for test data.

8123-472003 Check Valve

A Spartan Aircraft check valve of the size required for the SRLD had a minimum pressure drop of 30 psi. Spartan would not accept a contract to supply a unit with a maximum drop of 10 psi unless a development program was authorized.

A James, Pond, Clark "Circle Seal" check valve was selected and tested. The valve "as is" would not pass low reverse pressure leak tests because of the Teflon dynamic seal "O" ring. This was replaced by a Viton "A" 'O' ring and successfully passed flow and leakage tests. See Figure 14 for flow test results.

8123-472015 Pressure and Vent Valve

This is a manually-operated push-pull spool type valve designed for the Mercury Program. In the push position, it keeps the tank vented and shuts off source gas to the tank, and in the pull position it allows source gas to flow to the tanks and closes the overboard vent line. This valve has been developed for 100 cycle life operation and operates over a pressure range of 0 to 525 psi. It has also been designed for compatibility with hydrogen peroxide systems.

The accountability of two "Mercury" units (8060-472036) were transferred to the SRLD program. An additional unit is being manufactured solely for the SRLD program.

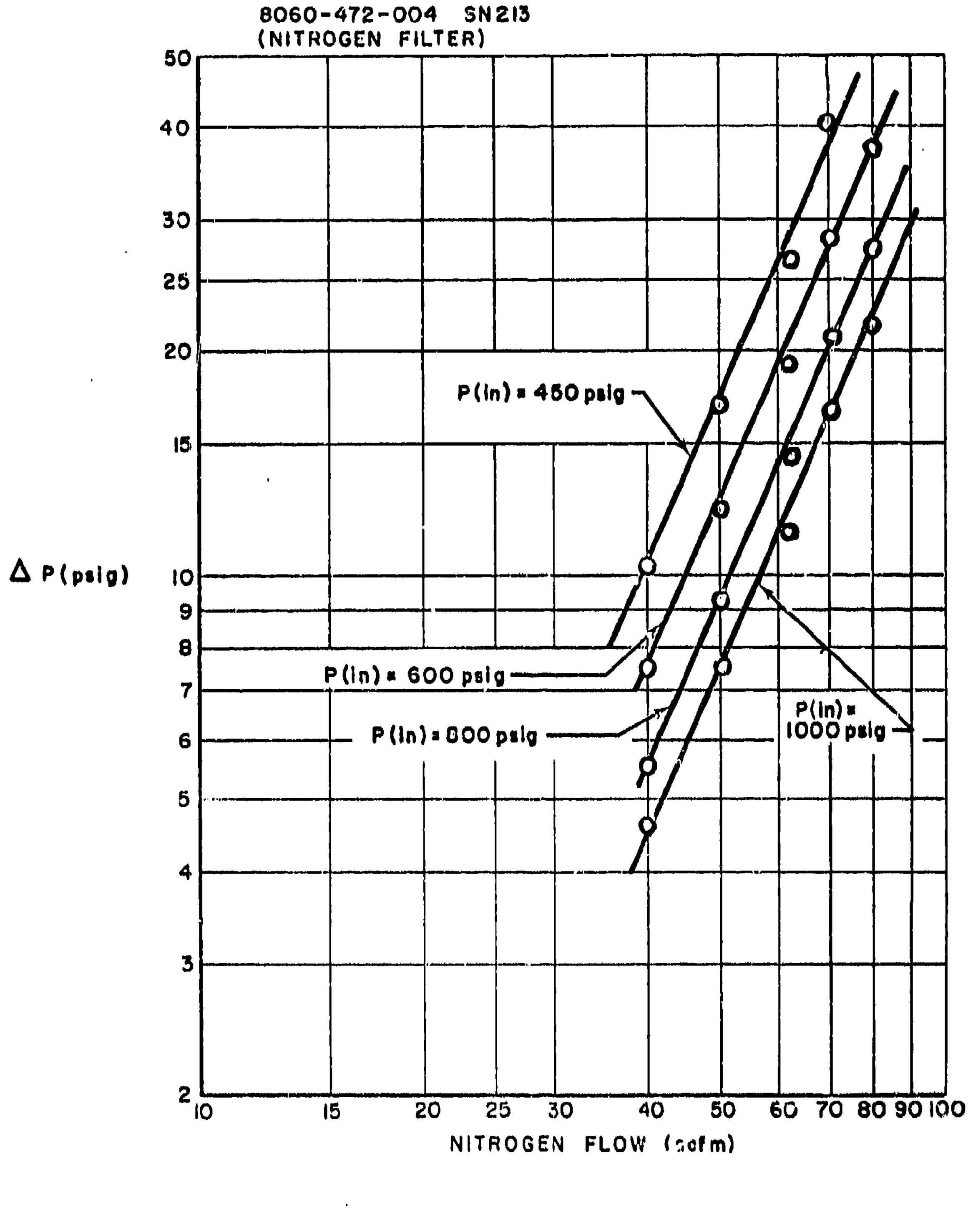


Figure 13. N_2 Gas Flow vs ΔP (N_2 Filter)

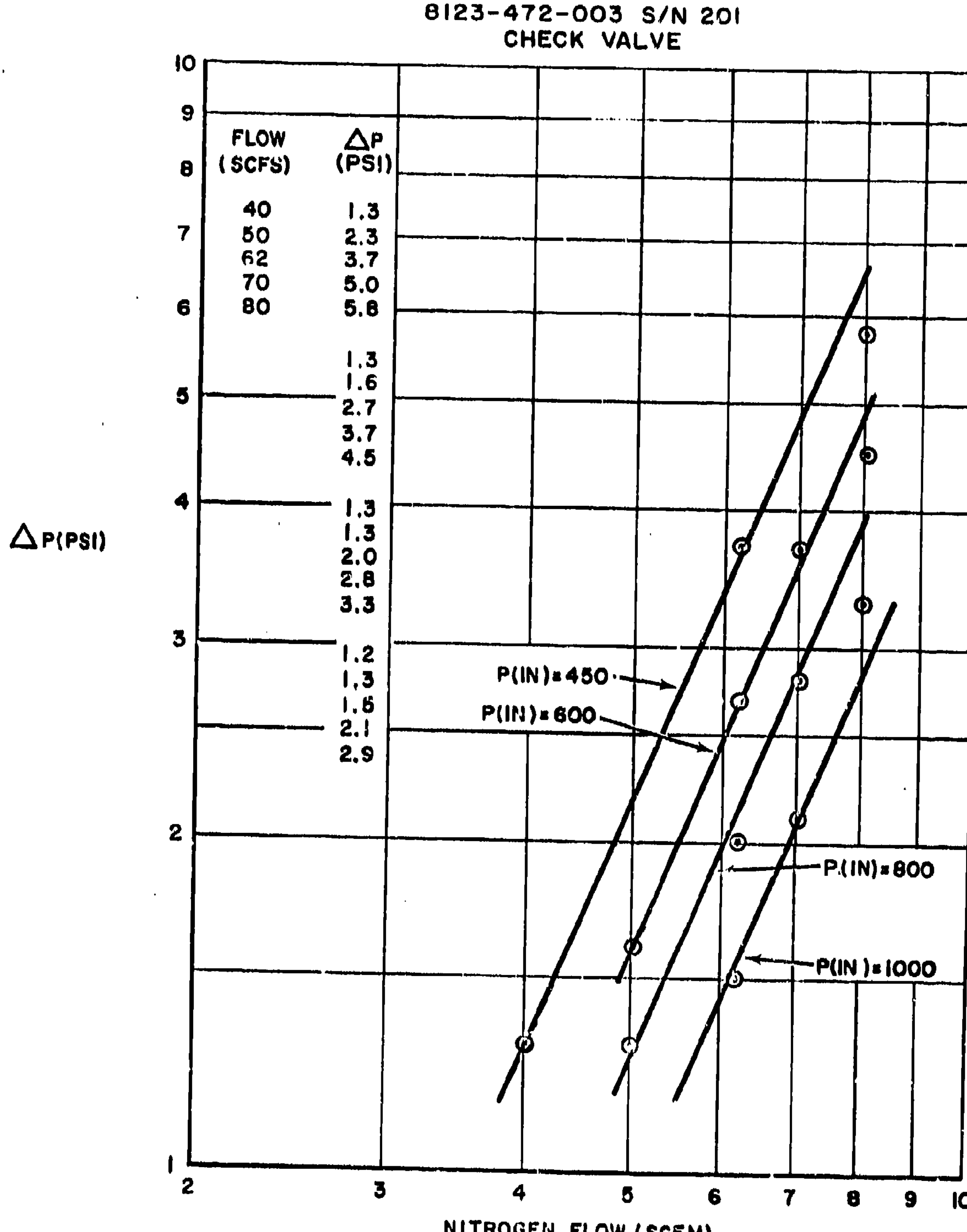


Figure 14. N_2 Gas Flow vs ΔP (Check Valve)

Problems encountered with this valve were "O" ring blow-out due to wire-drawing of the soft durometer silicone (DC 9711) "O" ring during pressurization, and maintaining the piston in the vent position because of the slight pressure unbalance.

The following modifications were made to the valves to overcome these problems: The first problem was overcome by changing the "O" ring compound to Viton "A" which has greater tear resistance. The second problem was resolved by adding a ball detent which held the piston in the tank vent position.

Pressure drop test data on this unit is shown in Figure 15.

8060-472122 Relief Valve

This is a spring-loaded soft-seat type valve designed for use in a hydrogen peroxide system for the Mercury Program. The life cycle is over 500 cycles. Cracking pressure range is adjustable from 500 to 600 psi and reseat from 450 to 550 psi. Leakage does not exceed 5 cc per hour at reseat and lower pressures. At fully opened positon, the valve will pass approximately 75 SCFM nitrogen gas.

Two of these units were procured from the "Mercury" program and are being used in the "as is" condition for the SRLD program. An additional unit is being manufactured for the SRLD program. The following test data was taken from the first unit.

	Specified Pressure	1	2	3	4	5
Cracking Pressure	535-580 psi	551	550	549	550	550
Reseat Pressure	480 psi Minimum	525	523	524	523	523

Zero leakage after reseat up to 15 minutes was observed.

1525-316SS Low Pressure Gauge 0-600 psi

Two stainless steel gauges, 0-600 psi, purchased from U.S. Gauge Company for use in the hydrogen peroxide system were successfully cleaned and conditioned for peroxide service. See Figure 11 for calibration curve presentation.

8123-471001 Hydrogen Peroxide Storage Tank Assembly

Two sets of Hydrogen Peroxide tank assemblies were made from standard D_2 type oxygen bottles. One set was proof, fatigue and burst tested. See Figure 16. The other set was proof tested and is now installed on the SRLD.

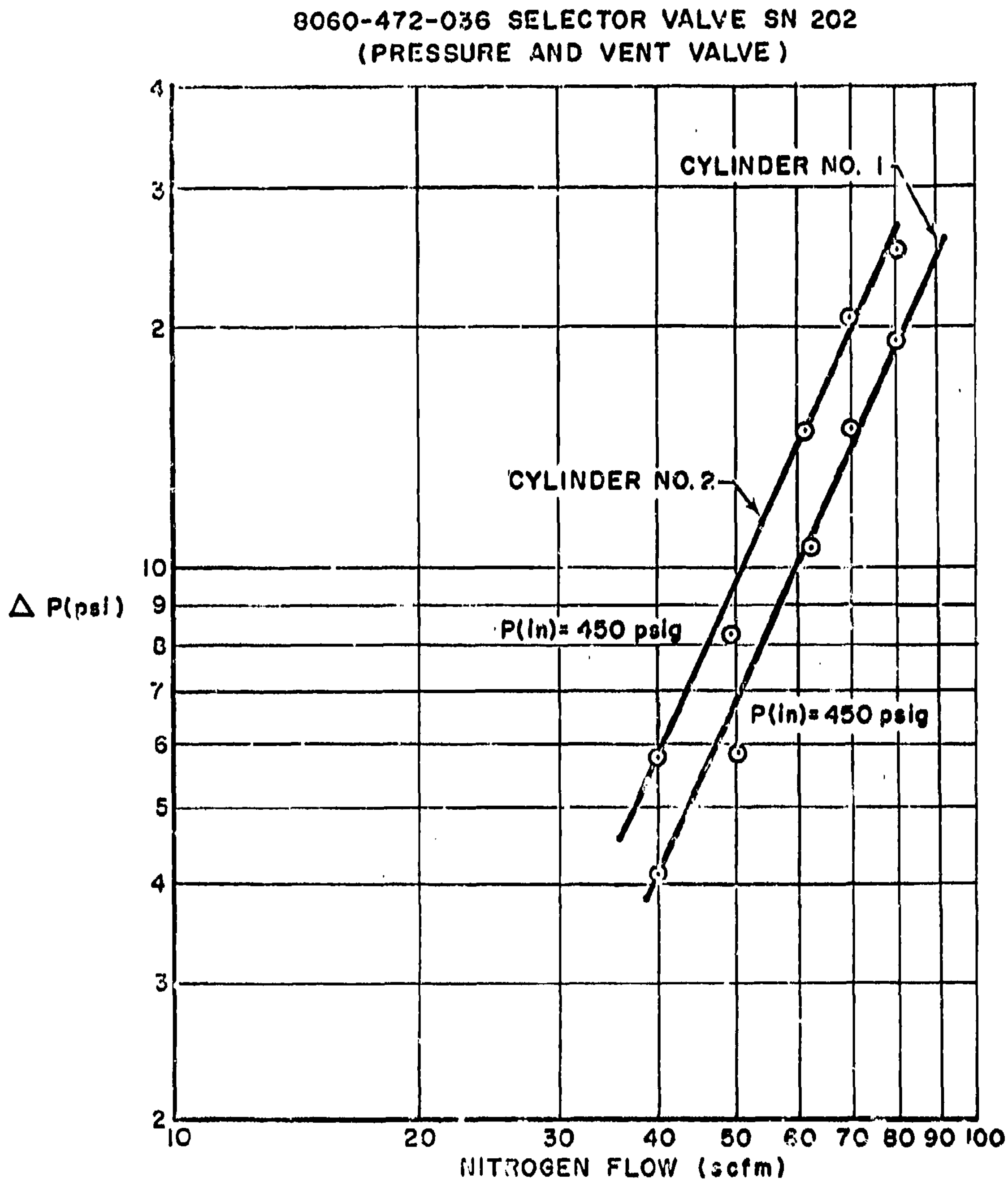


Figure 15. N_2 Gas Flow vs ΔP (Pressure and Vent Valve)

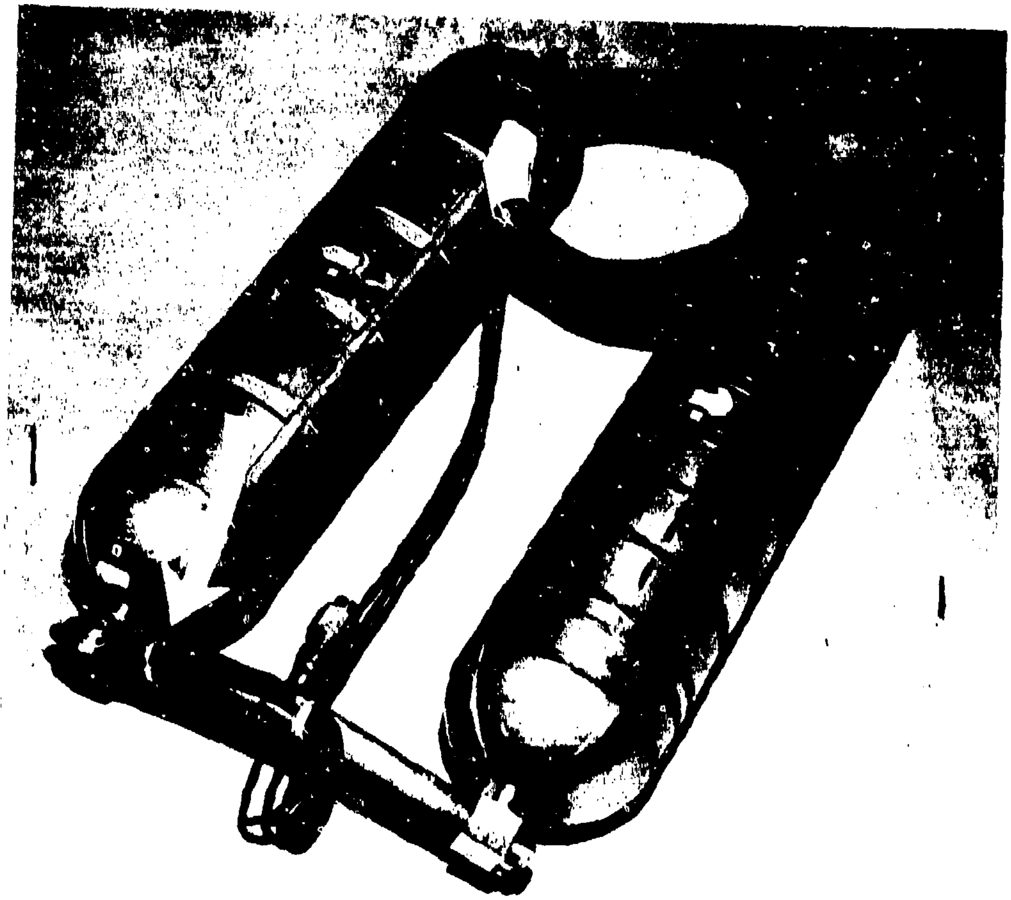


Figure 16. SRLD Burst Test Tanks

The proof test pressure was 788 psi. Figure 17 presents the displacement and permanent set curves of the first set of tanks. Fatigue testing consisted of 2000 cycles of 0-525 psi pressure, during which no leakage occurred. On the burst test, at 1150 psi a crack developed in the weld at the left-hand outlet fitting. Figure 18 is a displacement and set curve derived from test data during burst test. Figure 19 shows the proof test displacement and permanent set curve of the set of tanks now installed on the SRLD.

8123-472005 Manual Fill, Drain and Bleed Valve (2 Required)

In order to reduce the weight and envelope configuration of the original 8060-472009 valves it was decided to go to smaller valve. A "Shrike" bleed valve (59-472-275) was selected because of its size and weight (approximately 1/4 of the original valve). For compatibility with hydrogen peroxide it was necessary to modify these valves by removing the chrome plating from the needle detail. This valve is also being used as a shutoff valve in the fill bleed system.

8123-472002 Throttle Valve

Early in the design phase of the propulsion system, the throttling characteristics required for the SRLD were determined. It was desirable to attain approximately 70 percent thrust with approximately 35 percent of the initial throttle stroke, and to reserve the remaining 65 percent of the throttle stroke for vernier thrust control between 70 and 100 percent. This feature provides good, sensitive hovering control as propellant is utilized during the flight. The foregoing throttle valve characteristics are presented in the curve in Figure 20. Two additional characteristics assigned to the design of this valve were: positive shutoff at the end of the stroke, and low breakout and running friction to allow smooth throttling action. The valves were designed and fabricated by the National Water Lift Company of Kalamazoo, Michigan. Design, fabrication, preliminary test, and delivery was accomplished by them, on schedule. Tests at Bell confirmed that the throttling flow and shutoff characteristics of both valves were within specification tolerances, and they met 90 percent H_2O_2 compatibility requirements. However, when one valve was installed on the SRLD gas generator test stand for hot firing evaluation, trouble was encountered with high breakout friction, sticky operation and shearing of the shutoff "O" ring by the plunger. Tests were continued after removal of the shutoff "O" ring and lubrication of the "Viton" running "O" ring seals. The resulting leakage of 150 cc/min. at operating pressure was considered acceptable for temporary use. The second valve was returned to the vendor for redesign and rework as required. As a result, the following changes were made:

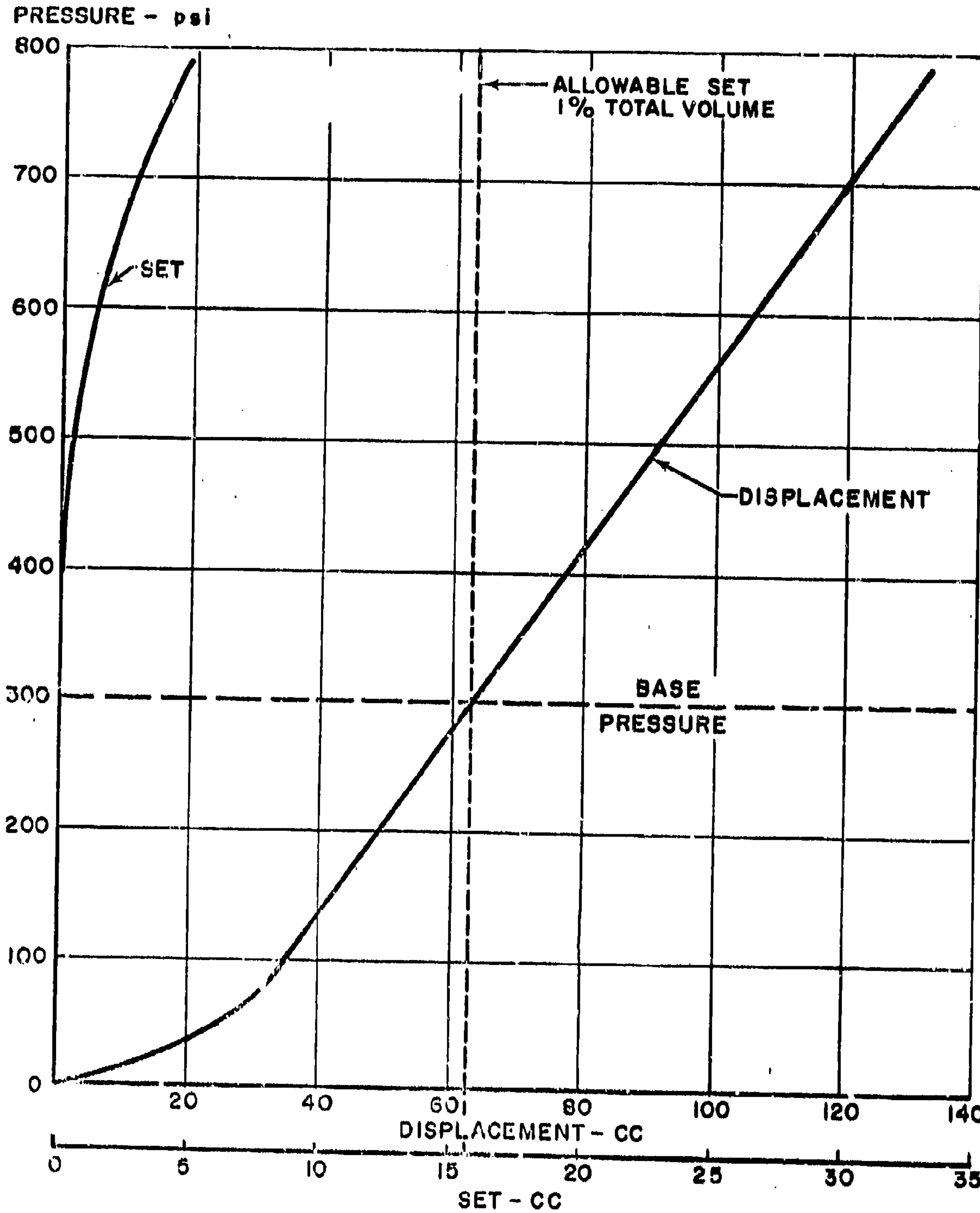


Figure 17. Proof Test Displacement and Permanent Set Curve, Burst Tanks

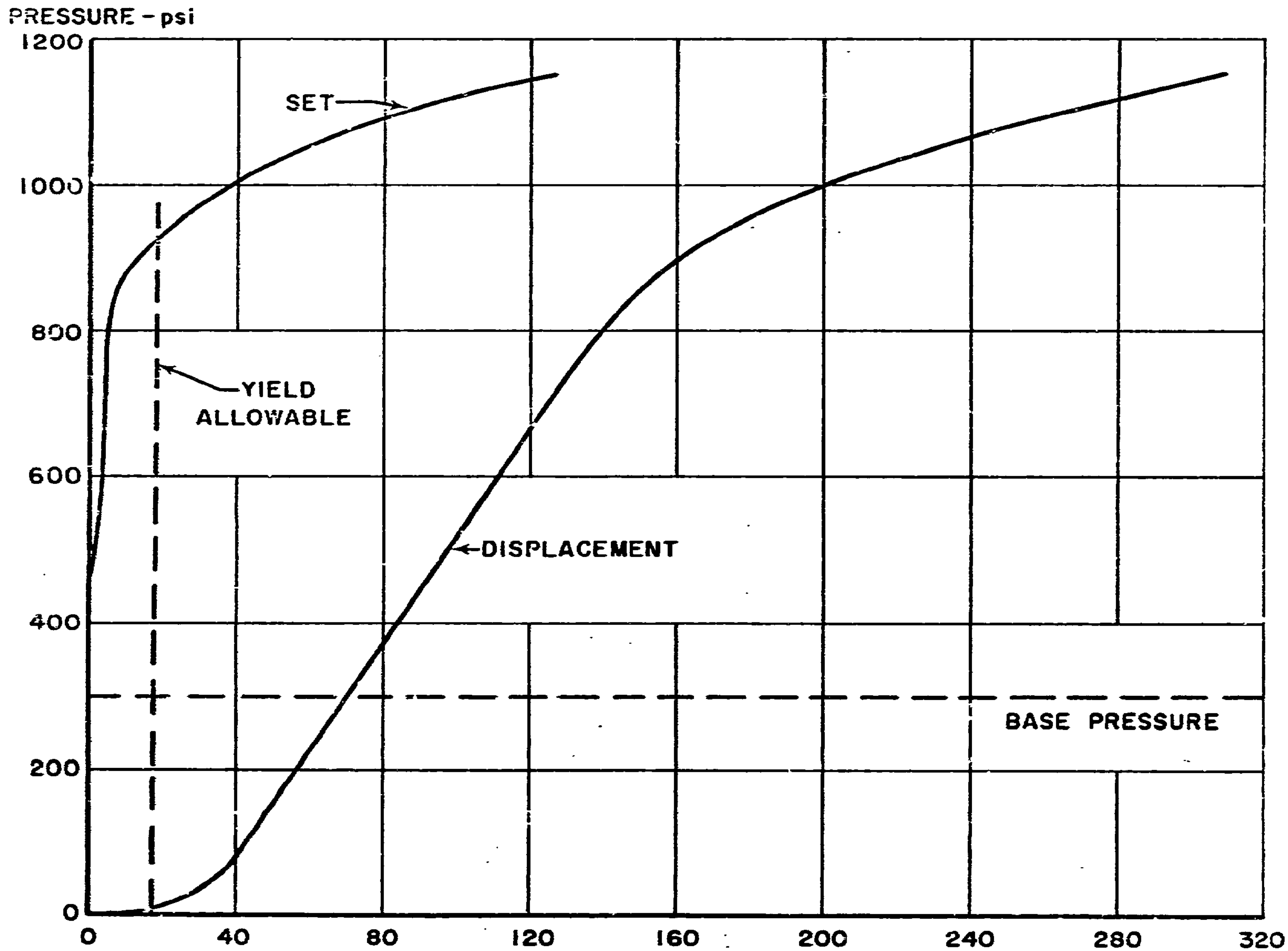


Figure 18. Burst Test Displacement and Permanent Set Curve

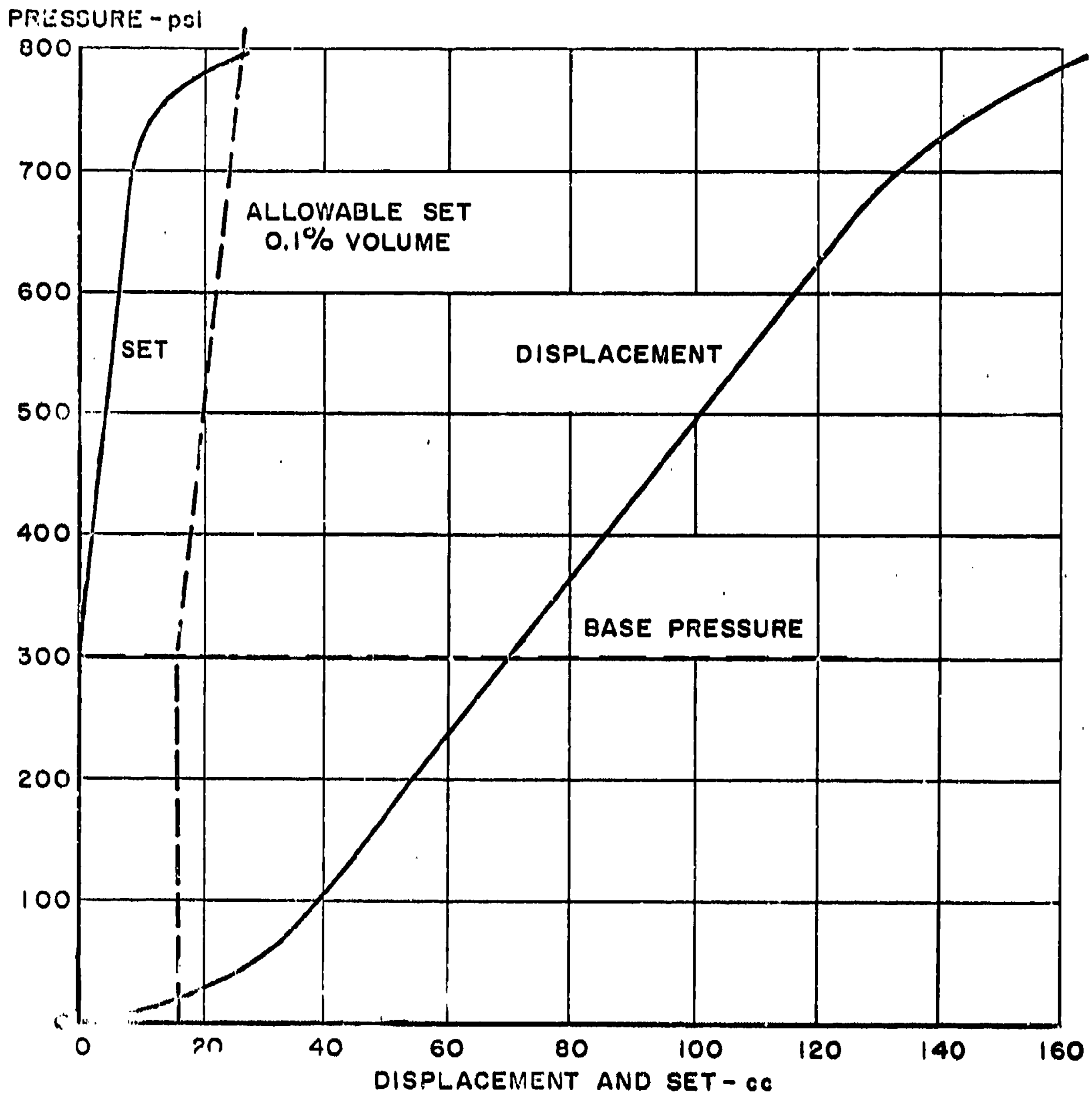


Figure 19. Proof Test Displacement and Permanent Set Curve, First Flight Tanks

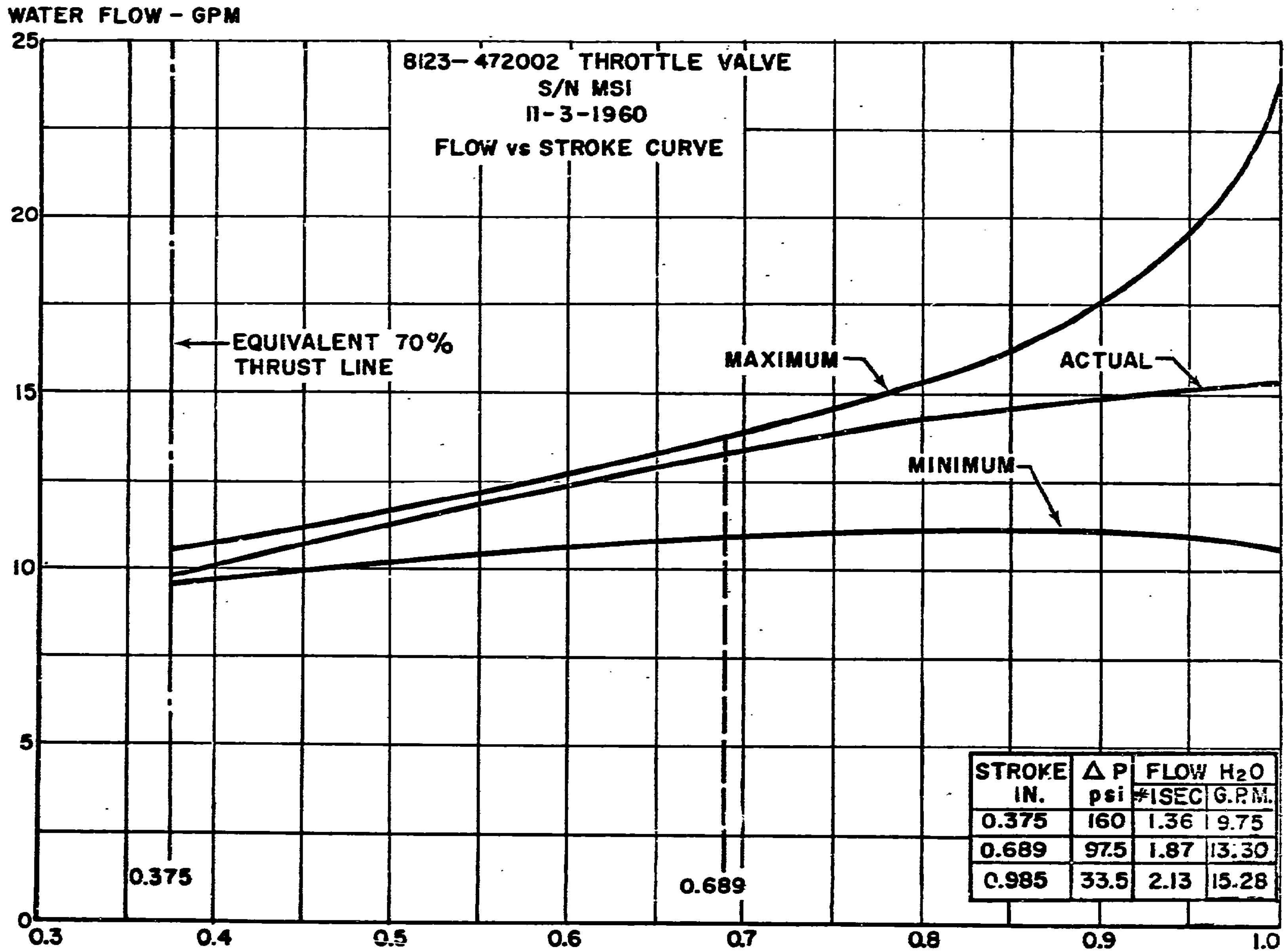


Figure 20. Throttle Valve Water Flow Test Curve

1. The shutoff "O" ring seal and groove were removed.

2. New, close tolerance plunger and spool were installed.

3. The flow annulus around the initial throttling orifices was removed.

4. Teflon-capped dynamic "O" ring seals were installed.

As a result of these changes the valve now works smoothly, with a breakout force of five pounds and running force of 3.5 pounds. Leakage in the shutoff position, at maximum operating pressure, is 1.6 cc/min.

The second valve will be returned to NWL for rework and returned to Bell for additional testing.

8123-470001 Gas Generator Assembly

The hydrogen peroxide gas generator is of a conventional design which has proven its reliability efficiency and endurance in many similar applications. The essential and performance-controlling component is the catalyst bed. Catalyst material is the Bell Type 7 catalyst screen.

Specific impulse varies somewhat when a rocket motor or gas generator is throttled from the design point. This factor must be taken into consideration when calculating theoretical SRLD flight times. For this pupose, curves of gas generator I_{sp} and flow rate versus thrust are presented in Figure 21.

The gas generator chamber is constructed of 347 stainless steel and of an all-welded design to avoid any possibility of leakage. A sufficiently large chamber volume downstream of the catalyst bed ensures an equal flow distribution into the two hot gas branches leading to the nozzles.

The external surface of the gas generator is enveloped by a perforated heat shield to avoid skin burns on accidental touch.

Test firing of the gas generator began in October 1960. The catalyst bed was conditioned for 250 seconds. Because no performance discrepancy was evident, it was decided to proceed immediately with reliability testing. A total of 88 firings were conducted with close monitoring of all performance parameters (see Appendix IV). Results of these tests are shown in Figure 22. The majority of these tests used the fixed nozzle configuration. However, because the test program was proceeding without complications, it was decided after Run 47 to install the flexible nozzles of the ball joint type into the system to

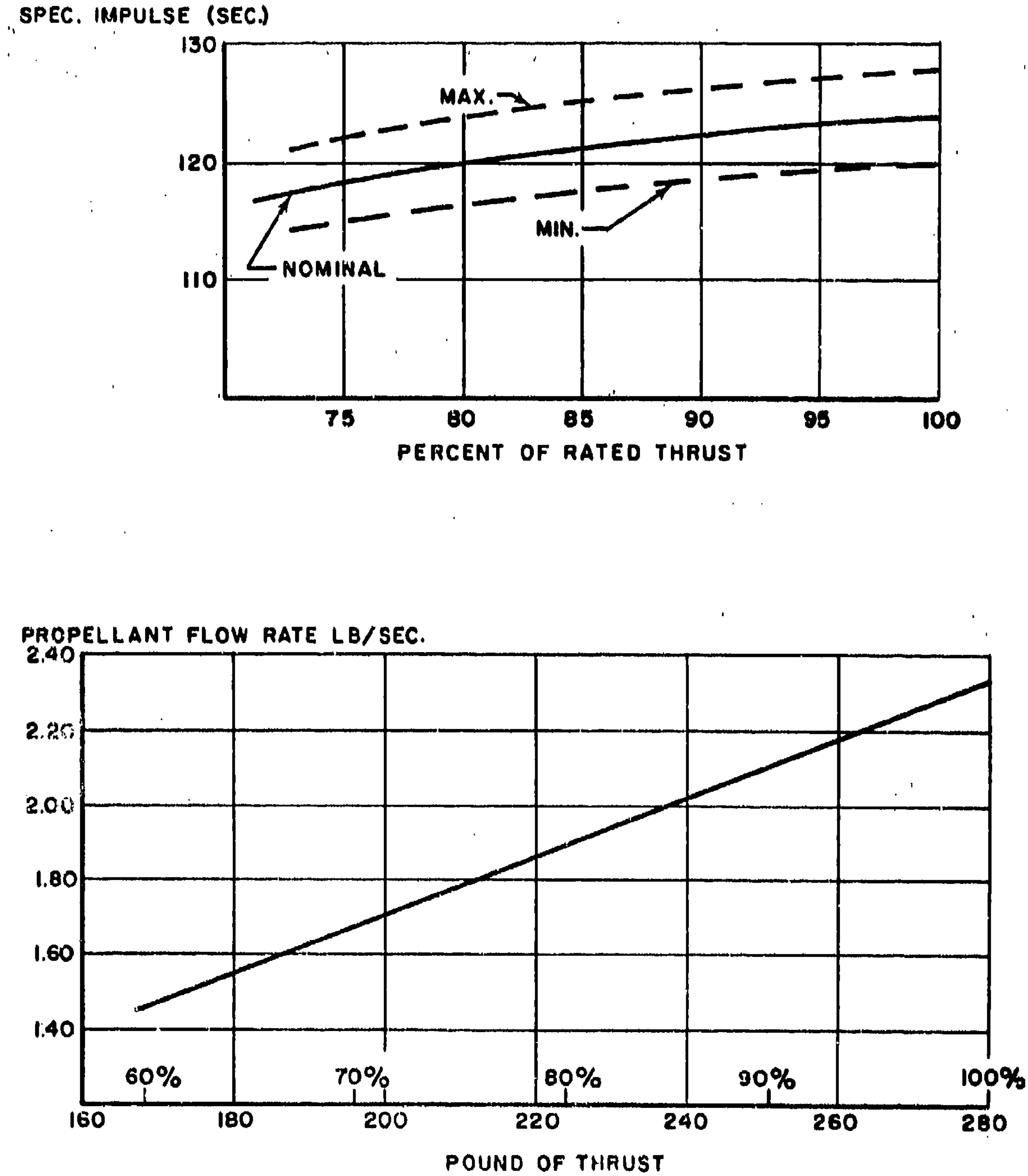


Figure 21. SRLD Specific Impulse and Flow Rate vs Thrust

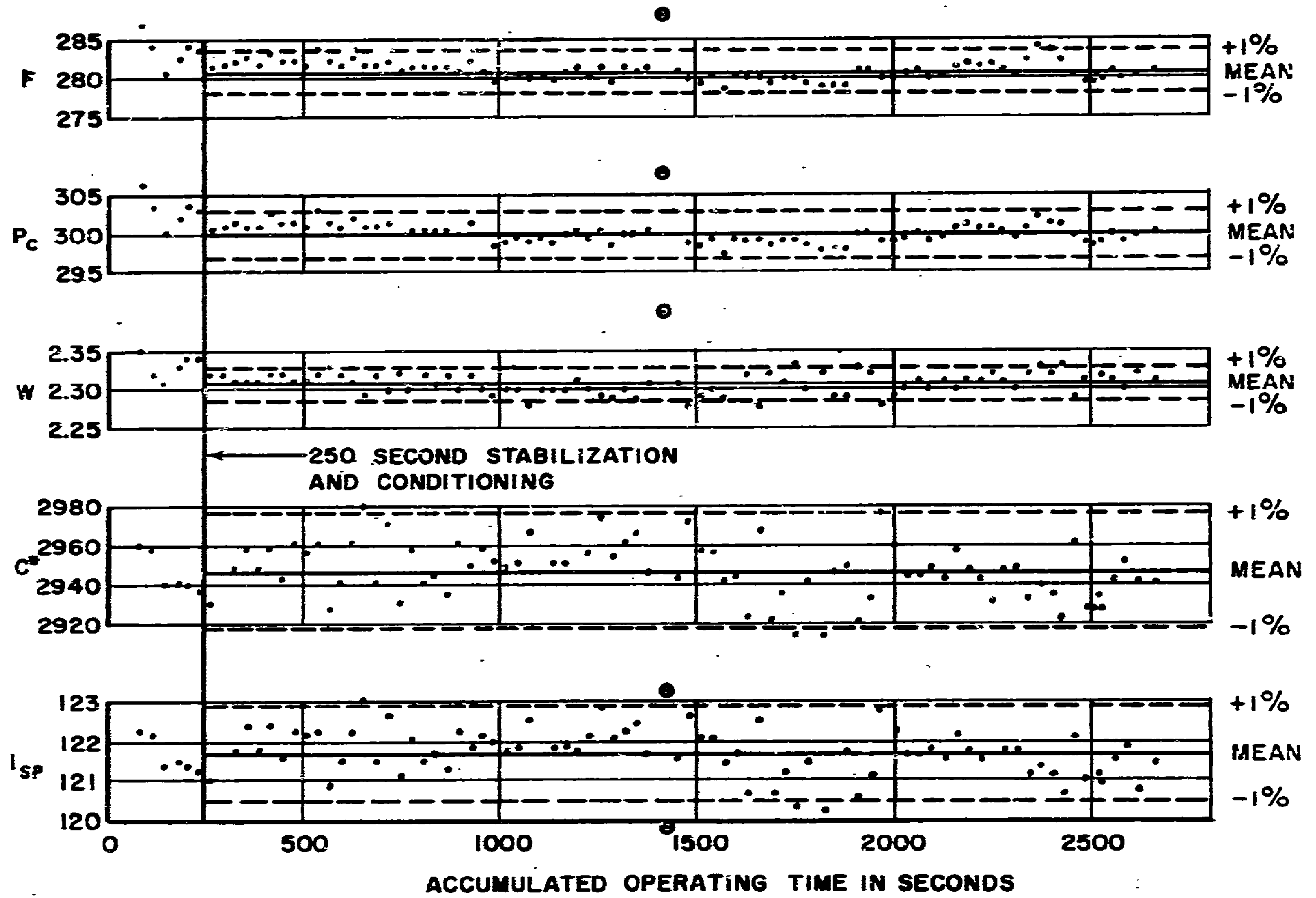


Figure 22. Gas Generator Performance, Reliability Tests

obtain information about their operating characteristics. Observed frictional forces were excessive and the nozzles were locked for the remainder of the reliability test program.

On Run 85 a test was made to determine what the maximum temperature of the feed line H_2O_2 would be if the SRLD were fired for 30 seconds and shutdown without purging or venting. This is a safety consideration. This temperature was found to reach a maximum of 170°F at 22 minutes after shutdown and is considered safe. Figure 23 is a time-temperature curve from this test.

8123-470040 Gimballed Nozzle Assembly

The lift-producing nozzles are of the swivel type to provide flight control. The nozzles are fully gimballed and can be deflected in a complete circle at an angle of 9 degrees. However, an inboard stop prevents deflection towards the body of the pilot.

Figure 24 shows the design approach taken by Bell Aerosystems Company to develop a swivel-type nozzle.

Testing of the original ball joint flexible nozzles revealed high frictional forces under axial loads induced by internal pressures on the nozzle and inner race. These frictional forces are amplified by wedge action between the inner and outer race under axial load. The forces required to deflect the nozzles were found to be 150 to 300 inch-pounds at the end of a 30 second firing period, virtually resulting in seizing of the joint while hot. A redesign was immediately initiated with the following objectives.

(1) Relocate the nozzle throat, axially, to balance the dynamic pressure forces of the convergent and divergent nozzle to a possible optimum to reduce axial loads.

(2) Reduce ball joint diameter to a minimum to reduce the magnitude of unbalanced cross-sections and axial forces.

(3) Utilize external gimbals to take axial loads and provide low-friction, high-temperature seals on the spherical surfaces between the two moving nozzle sections.

Design illustration "C" in Figure 24 was selected for fabrication. Cold actuation torque on these nozzles was very low with pressure on the seal adequate to seal properly. Subsequent hot firings showed that the friction feel of the gimballed nozzles seemed no different than the cold static "feel".

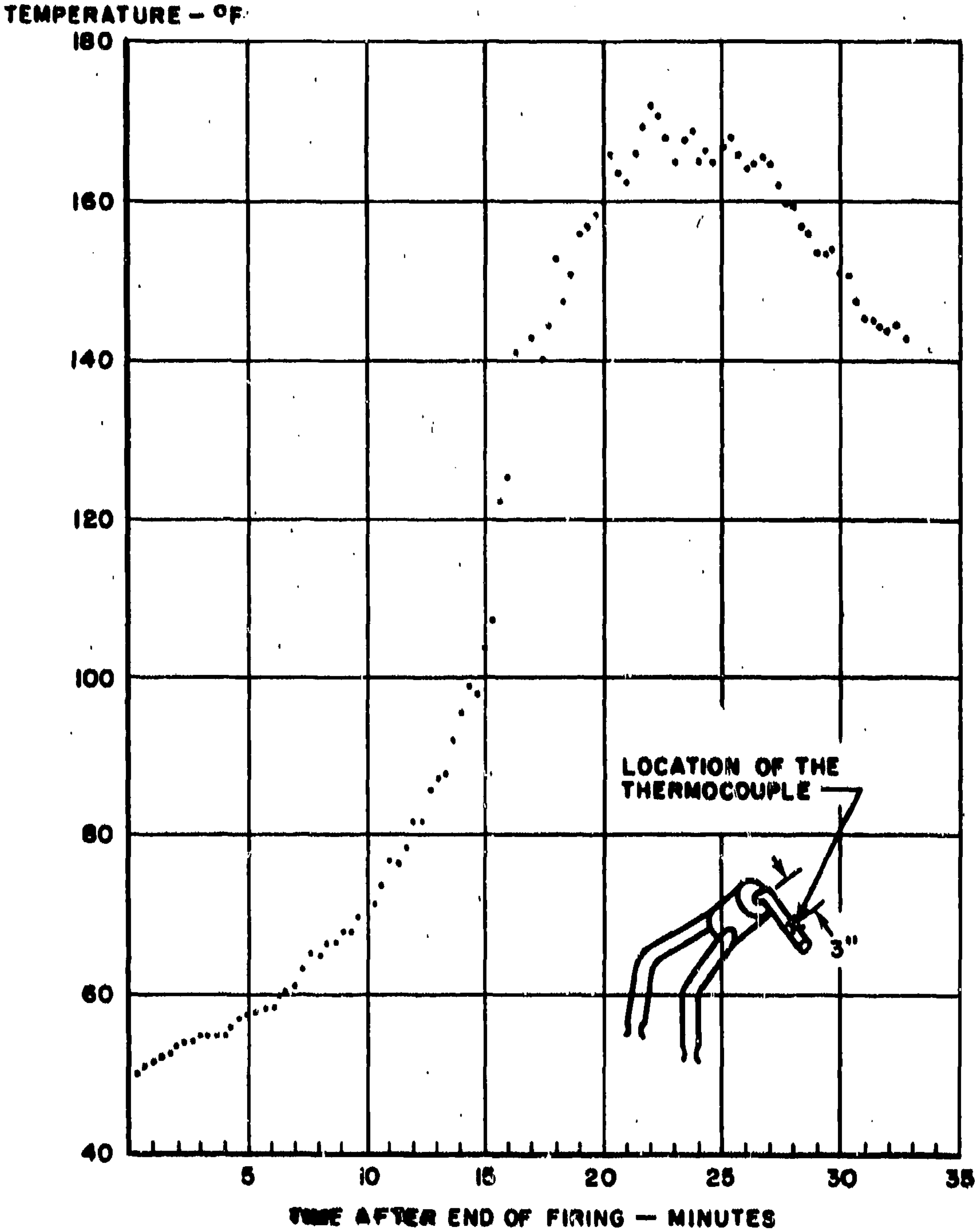


Figure 23. Feed Line Temperature Curve

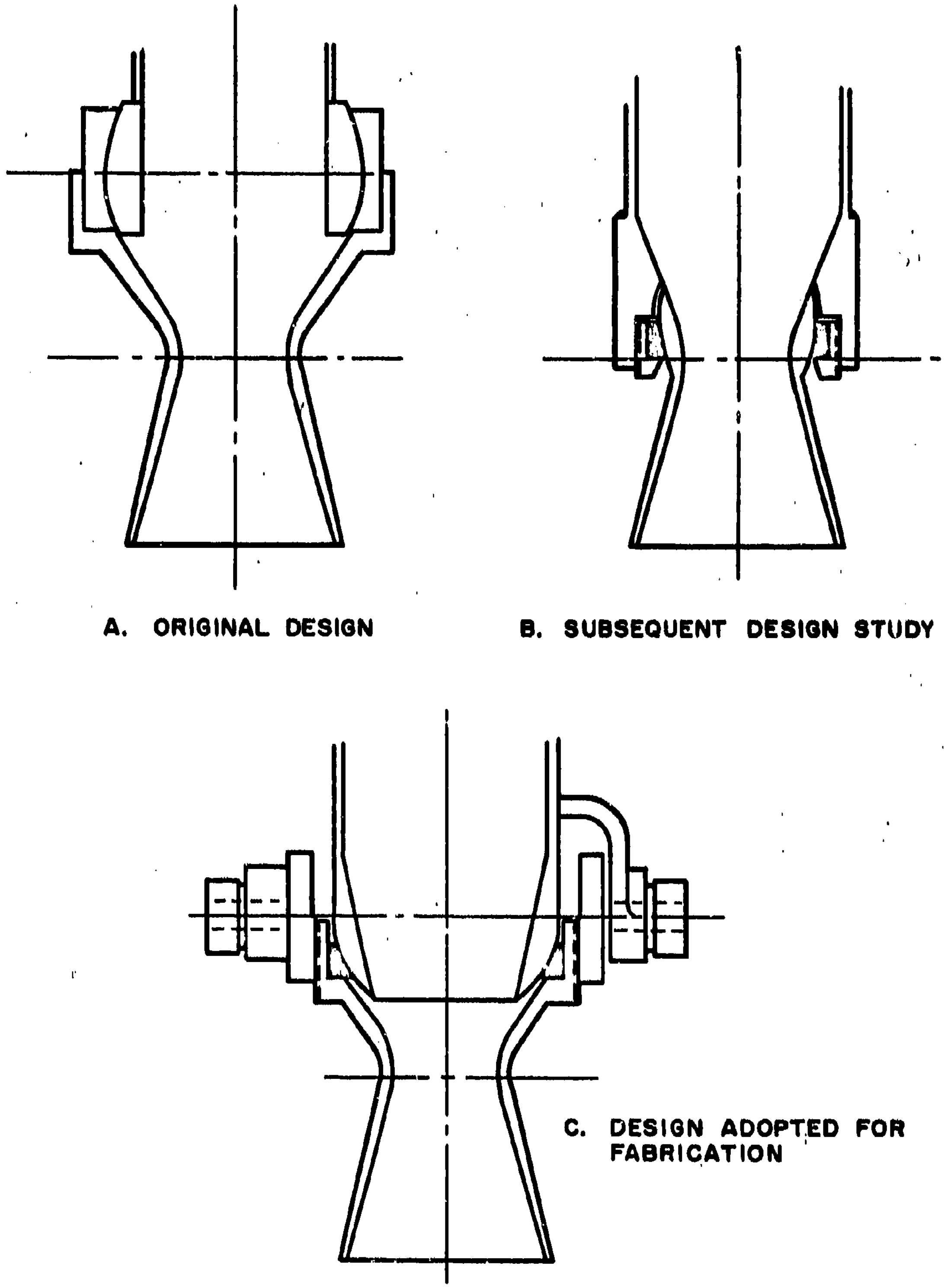


Figure 24. Flexible Nozzle Design Approaches

However, the friction level is deemed high enough to demand an excessive weight to overcome it, if the automatic stabilization system is to be used. Insomuch as this system is not deemed mandatory for safe flight control, it was decided to "wring out" the other methods of control and install this system later if required.

III. STABILITY AND CONTROL

Studies were made of the controlled lateral behavior of a man supported by the SRLD. System dynamics were instrumented on an analog computer and control inputs were provided by a human operator who responded to visual cues displayed on an oscilloscope (Figure 25). The analog studies indicated that a stability augmentation system may not be necessary for satisfactory control. Control moments reduced from original design values resulted in highly improved handling characteristics. Preliminary Phase II tethered flight tests have not reached the stage where correlations between flight test observations and the computer studies can be made.

Early tethered flights on SRLD test rigs powered by compressed nitrogen showed certain undesirable stability and control characteristics. Fore-aft pitching and translation were satisfactory but lateral translation and rolling motions were oscillatory and for the most part uncontrollable. In order to obtain a better understanding of the system dynamics, a mathematic model possessing some of the basic properties of a man supported by a rocket lifting device was simulated on analog computing equipment. Initial studies were concerned mainly with the effect of a stability augmentation scheme on the uncontrolled lateral behavior. Subsequent studies were then made to determine how certain parameters influenced the controlled behavior by a man whose task was to hover and translate laterally. These latter studies are discussed in this report.

A. METHOD OF ANALYSIS

The model of the man-machine combination and stability augmentation device used in this investigation is shown in Figure 26 along with the applicable equations of motion.

This model has an upper and a lower body connected by a torsional spring at a point corresponding to the hip axis. Rocket nozzles are located at the end of L-shaped arms assumed to be rigidly attached to the upper body. The upper body represents the man's upper torso, head, arms, propellant tanks, gas generator, valves and tubing. The lower body represents the legs. Except for the hip spring, this model is similar to the one developed in Reference 2. Small-angle approximations were used in the derivations. Effects of variable mass and moment of inertia due to propellant consumption were neglected. The equations were instrumented on an analog computer.

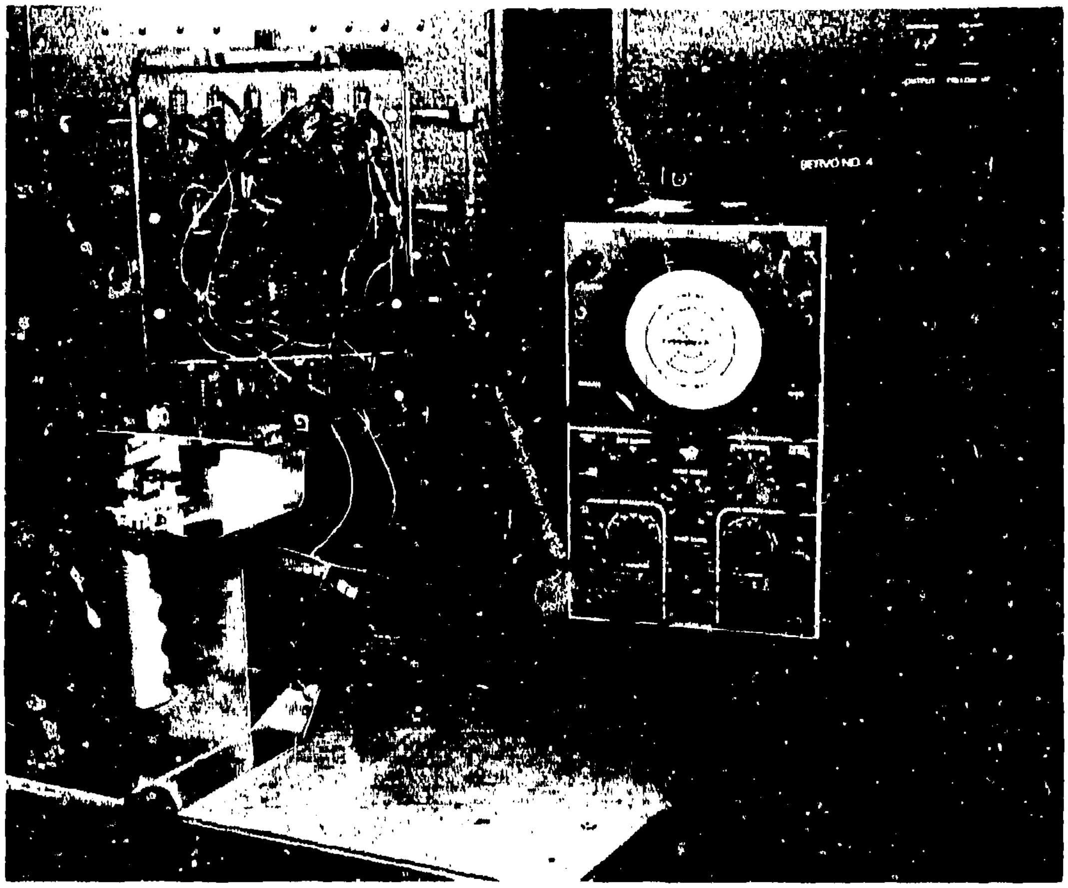
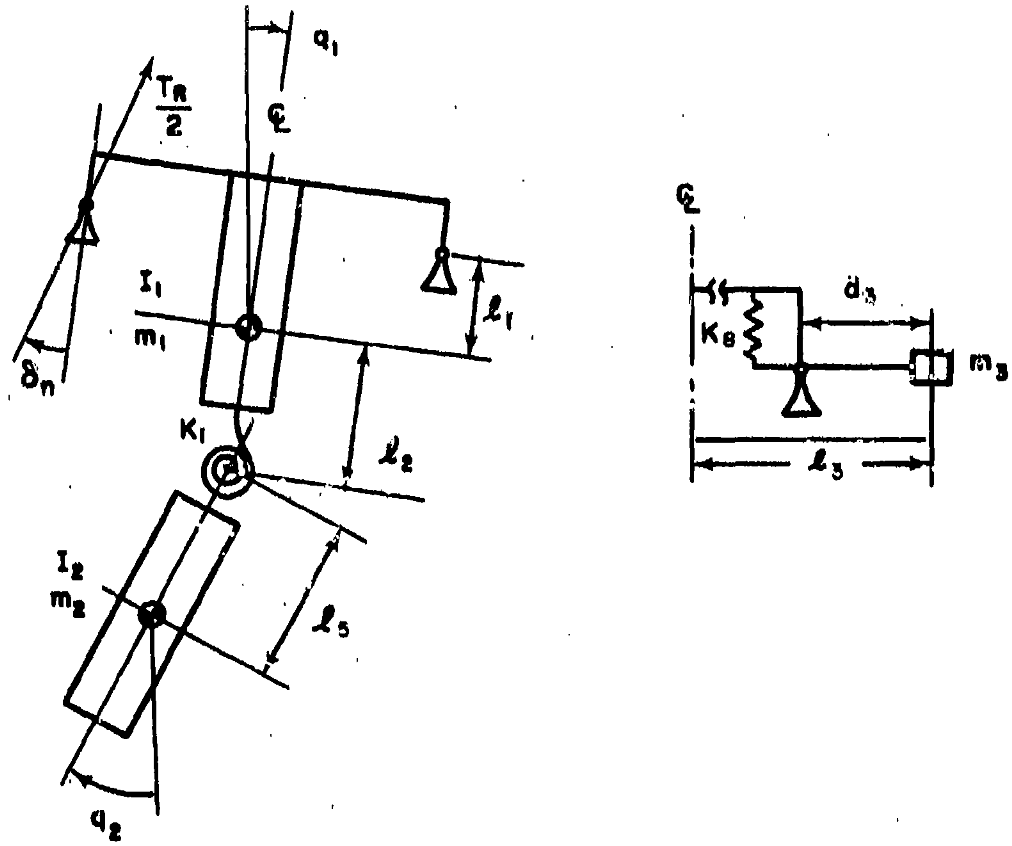


Figure 25. Control Simulation Test Setup



$$I_1 \ddot{q}_1 - m_1 g \ell_2 q_1 - K_1(q_2 - q_1) + 57.3\, m_1 \ell_2 \ddot{x} = \frac{T_R}{2}(\ell_1 + \ell_2)\,\delta_n$$

$$I_2 \ddot{q}_2 + m_2 g \ell_3 q_2 + K_1(q_2 - q_1) - 57.3\, m_2 \ell_3 \ddot{x} = 0$$

$$57.3\,(m_1 + m_2)\ddot{x} + m_1 \ell_2 \ddot{q}_1 - m_2 \ell_3 \ddot{q}_2 = T_R q_1 + \frac{T_R}{2}\delta_n$$

$$\ddot{\delta}_s + 2\zeta\omega_n\dot{\delta}_s + \omega_n^2\delta_s = -\frac{\ell_5}{d_3}\ddot{q}_1$$

$$\delta_n = \delta_c + \delta_s$$

Figure 26. Schematics of Man-Machine Combination and Stability Augmentation Device; Equations of Motion

Provisions were made for limiting the deflections of the stability augmentation system (δ_s) as a function of the nozzle control deflection (δ_c). This relation is inherent in the control system design and is shown in Figure 27.

The human operator or pilot was required to control his motion based on observations of his position and motion displayed on an oscilloscope screen. Figure 28 is a schematic of the display and shows the image seen by the pilot. The image height was adjusted to slightly over 1/2 inch. Thus its height to displacement ratio would give the impression that the image represented a 6 foot rigid man.

The method of analysis in Reference 2 did not employ a human operator. There, tasks were given to the man-machine combination in the form of specific translations at predetermined height. Control inputs were introduced on the basis of assumed fixed response characteristics of a human to stimuli such as height deviations, ground plane distance deviations, velocity, and acceleration. True trajectories based on these control inputs were then computed on digital equipment. One interesting analysis concerned the trajectory after a forward leg kick of assumed duration and nature. This may be, it seems, a good starting point for analytical studies of kinesthetic control characteristics by performing inverse analysis, i.e., given a prescribed trajectory, solve for the leg motions necessary to maintain the trajectory.

Although the digital computer approach offers advantages in the form of accuracy and the use of more detailed analytical expressions, the analog approach has the advantage of a human operator. Although his response characteristics differ between real and analog flights he can express judgement concerning the similarities and dissimilarities, desirable and undesirable behavior, especially if he has acquired tethered or free-flight experience. This was the case for two of the three pilots involved in the analog studies.

The actual prototype control stick was incorporated in the simulation. It was mounted on a sheet metal bracket and attached to a slide wire potentiometer whose output was fed to the computer.

In addition to the control stick, the actual SRLD has provisions for kinesthetic shoulder control. The nozzle arms are attached to a pivot bearing located behind the head and can be rotated by shoulder movements. This system was not, however, instrumented with the computer. The overall system block diagram is shown in Figure 29.

δ_c = NOZZLE DEFLECTION DUE TO CONTROL STICK

δ_s = NOZZLE DEFLECTION DUE TO STABILITY AUGMENTATION DEVICE

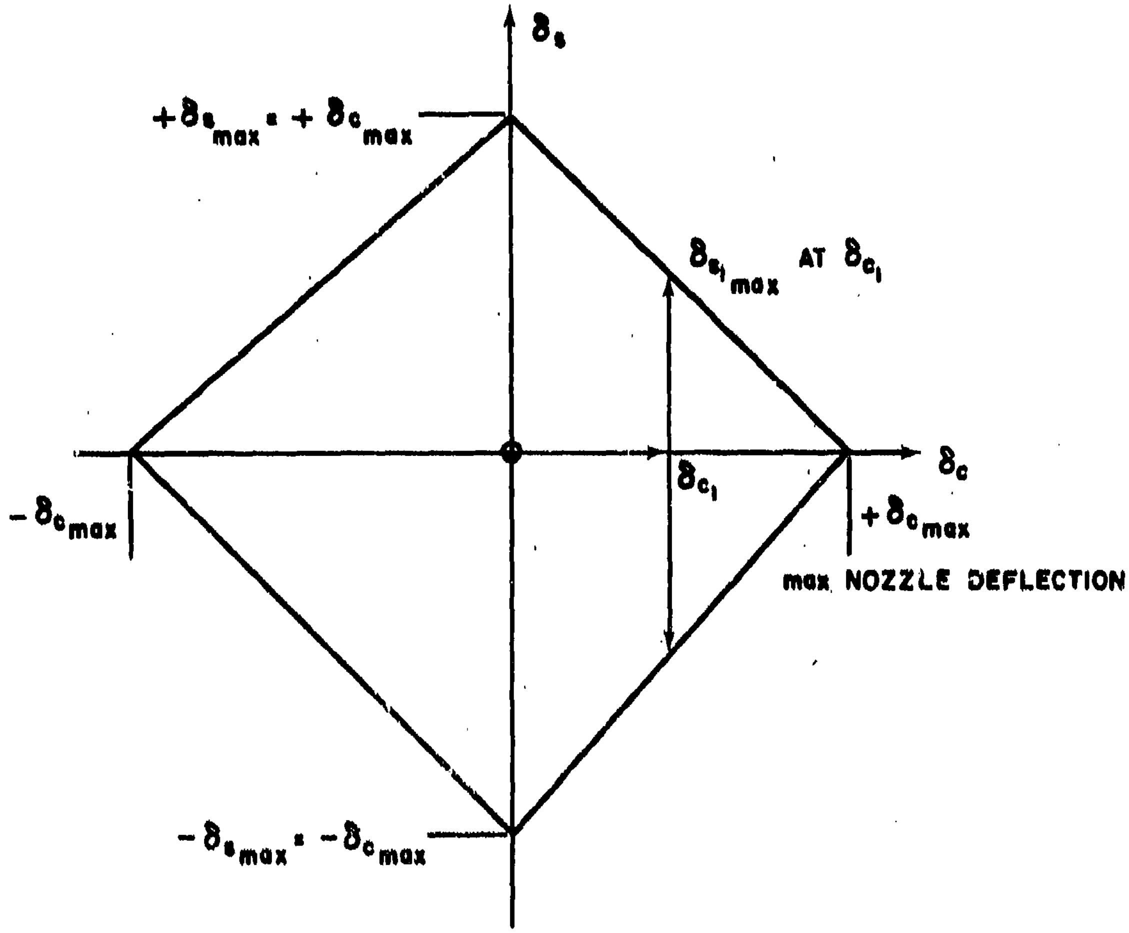
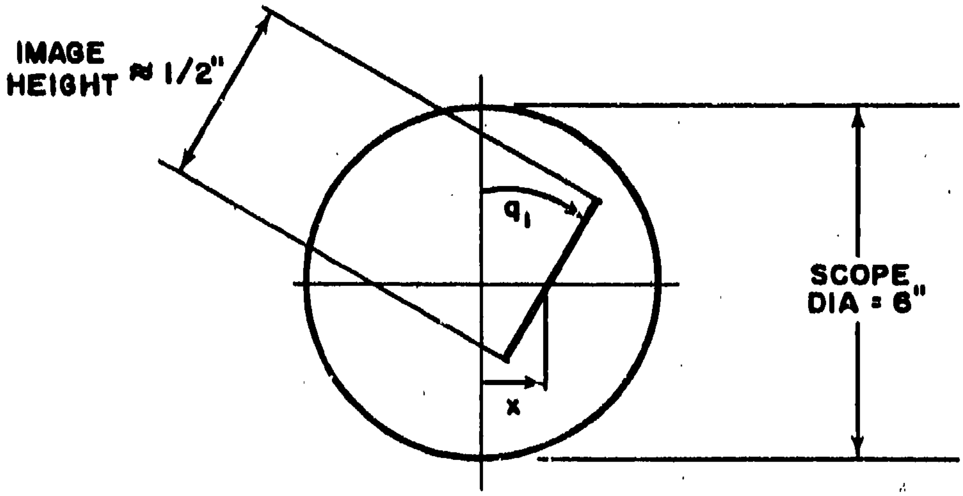


Figure 27. Stability Augmentation Deflection Limits as a Function of Nozzle Deflection Due to Control Stick



q_1 = UPPER BODY ATTITUDE, DEGREES

$x \propto$ LATERAL DISPLACEMENT, FT

SCOPE DISPLAY RATIOS:

1° SCOPE = 1° ATTITUDE

2" SCOPE ≅ 20 FT LATERAL DISPLACEMENT

Figure 28. Oscilloscope Display Schematic

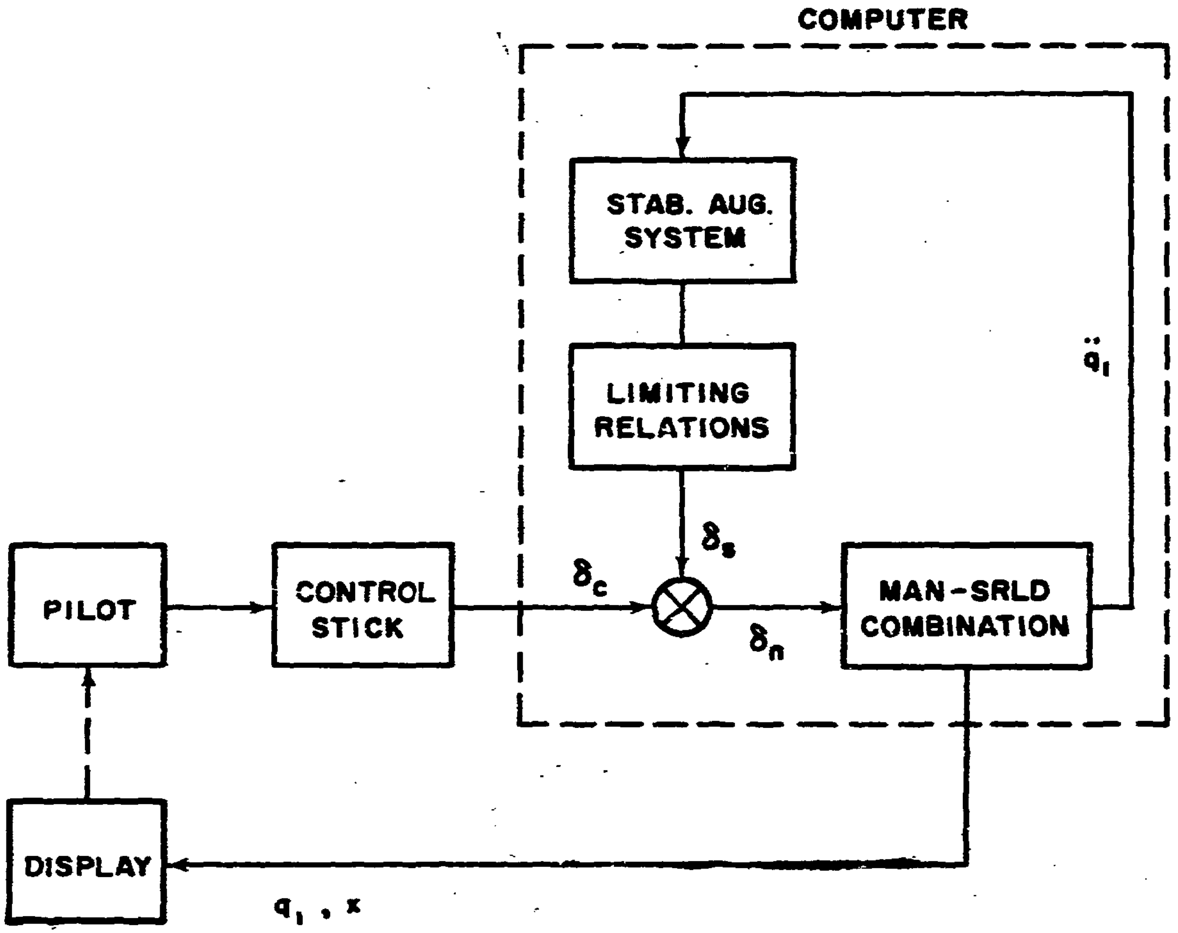


Figure 29. Over-all System Block Diagram

A systematic evaluation of the stability augmentation system was the first phase of the study. The object was to find the effect of frequency and damping on the controlled behavior of the man-machine combination, and if possible, to specify desirable values for design purposes. Twenty-five combinations of frequency and damping were chosen.

Following these stability system tests, the effects of other parameters were studied. These parameters included the hip-spring constant, upper and lower body moments of inertia, nozzle height above the gross center of gravity, and maximum nozzle deflection. The hip spring constant used for initial studies was an experimentally-determined value. It was obtained by suspending a man and measuring the force-deflection relation of his legs for a semi-relaxed condition.

A simplified pilot-rating system was used. This system (shown below) was chosen because of its simplicity and, being a comparative type, would quickly establish trends.

Letter Rating	Description
A	Very Good
B	Good
C	Fair
D	Poor
F	Uncontrollable

B. RESULTS AND DISCUSSION

First attempts to control the system were not successful, but as the study progressed and the pilots acquired learning time, their ability to control the system improved. The results of the first stability system tests are shown in Figure 30. Note that pilot A was given a velocity display. That is, the horizontal displacement of the oscilloscope image was proportional to lateral velocity rather than displacement. The velocity display was introduced to determine the effects of display response on the pilots' level of performance. Reference 1 shows that derivative information can have significant effects on pilot performance. This did not seem to be true for these tests and display effects were not pursued further. Figure 30c is a combination of Figures 30a and 30b. It separates the ratings into C-D and D-F groups. These results were not particularly gratifying since 39 of the 50 ratings were

ζ

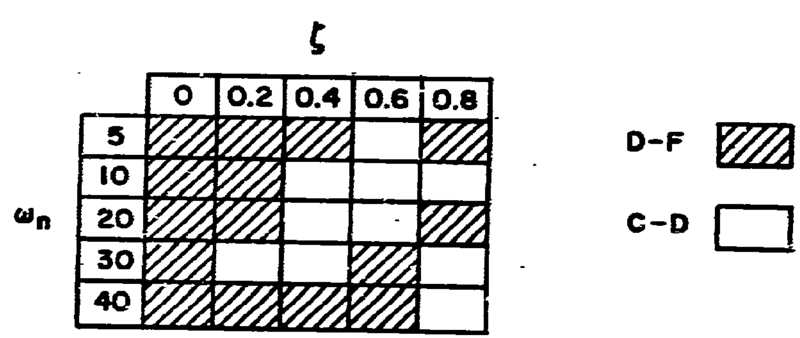
ω_n	0	0.2	0.4	0.6	0.8
5	F	F	D	C	F
10	F	D	D	C	D
20	F	F	C	C	F
30	D	D	D	F	C
40	D	D	F	D	D

(A) PILOT B

ζ

ω_n	0	0.2	0.4	0.6	0.8
5	F	F	F	D	F
10	F	D	C	C	C
20	D	D	D	D	D
30	D	C	C	D	D
40	F	D	F	D	C

(B) PILOT A (VELOCITY DISPLAY)



(C) COMBINED RESULTS

Figure 30. Results of Stability Augmentation System Tests

either D or F. It was concluded that:

1. Some damping in the lateral stability system is desirable.
2. The stability augmentation system might be of secondary importance.

Following these stability system tests,probes were made to determine which, if any, of the other parameters had significant effects on the controlled behavior. During these probes it was noted that the scope image maintained a hovering attitude if the pilot kept his hands off the control stick when the computer was turned on. When he attempted maneuvers the system soon became uncontrollable. These extremes — uncontrollable by pilot and satisfactory hovering with no control inputs — pointed to excessive control moments. With excessive control, spurious pilot-induced control moments result in rapidly occuring uncontrollable motions.

A series of runs were then made to determine the effects of maximum available control by changing maximum nozzle deflection and nozzle height above the gross center of gravity. Results are shown in Figure 31. Although most of the ratings are uncontrollable or nearly so, the difference, as noted by the pilots, between the 3, 6, and 9 degree deflections were definitely in favor of the 3 and 6 degree maximum nozzle deflections.

On the basis of these tests the SRLD hardware was modified by lowering the nozzle gimbal point from 3.75 inches to 2 inches above the gross center of gravity. The maximum nozzle deflections are easily adjusted on the SRLD. The 6 degree maximum deflection will be used in the first series of flight tests. This will give a maximum rolling moment of

$$T_{R\,max} = 280 \text{ lb}$$

$$M_{max} = \frac{T_{R\,max}}{2} \times \frac{6^\circ}{57.3} \times \frac{2}{12}$$

$$= 2.44 \text{ ft-lbs}$$

The maximum value used in Reference 2 is 12.5 foot-pounds. This rolling moment is obtained from maximum differential thrust of 10 pounds at a 15-inch moment arm. It is felt that the nature of analysis, i.e., digital vs pilot-controlled analog, account for this large difference. The roll-lateral translation motions are coupled, and pilots observing the oscilloscope display rated the total motion.

NOZZLE HEIGHT ABOVE GROSS C.G., IN.	MAXIMUM NOZZLE DEFLECTION, DEGREES		
	3	6	9
2	F	F	F
3.75	F	F	F
5	F	F	F
8	F	D-	F
11	D-	F	D
15	D-	F	D-
	PILOT A	PILOT B	PILOT A

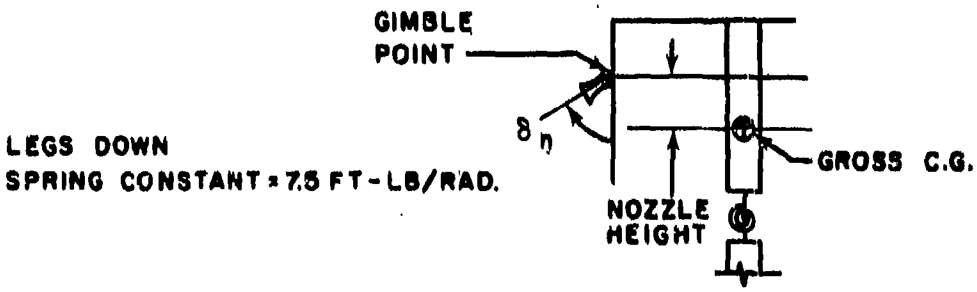


Figure 31. Effect of Maximum Nozzle Deflection and Moment Arm on Pilot Ratings. Inertial Exploratory Tests on Stability Augmentation System

The maximum stick deflection remained constant as the maximum nozzle deflection was varied. Thus, as the nozzle deflection was reduced from 9 degrees, its design value, to 6 and 3 degrees, the stick deflection-nozzle deflection gradient, as measured by $\frac{\theta_{K\,max}}{\delta_{N\,max}}$, increased by factors of 1.33 and 3.00 respectively. The effect of a constant deflection gradient for various nozzle deflections was not evaluated.

After those tests it was discovered that an increased value of hip-spring constant and moment of inertia of the lower body had significant effects on the system behavior. Figure 32a shows the effect of increased hip spring constant and Figure 32b shows the effect of raising the legs. Comparison of the results in Figure 31 and 32 shows that the hip spring constant has a primary influence on the controlled lateral behavior. It is probably one of the least accurately known parameters.

Short exploratory studies were also made to study the effects of mass and inertia characteristics on the controlled lateral behavior. There were slight but noticeable effects. More detailed studies may be in order at later stages of development.

During the course of the studies concerned with nozzle heights above the gross center of gravity, there appeared an interesting phenomenon which may be related to kinesthetic control behavior. Consider the two-segment body shown in Figure 33a. If a force is suddenly applied at some point above the gross center of gravity, the line joining the upper and lower centers of gravity will translate and rotate to the left. If the line of action of the force passes above the upper body c.g. it will excite the bending mode as shown in Figure 33b. If the line of action passes below the upper body c.g. it will excite the bending mode as shown in Figure 33c. At one time when the nozzle gimbal height was slightly above the gross c.g., this latter phenomenon was observed. For rapid control inputs the oscilloscope image, which represented upper body attitude, began initial angular motions in a direction opposite that desired by the pilot. This phenomenon was also observed on captive flight tests with nitrogen rigs.

As mentioned earlier the pilots became more proficient as the studies progressed. The direction of angular movement of the display image appeared to be the primary stimulus. When the pilots learned to lead this angular movement properly with the control stick, they could maintain the upper body attitude within reasonable limits. Lateral displacement seemed

HIP SPRING CONSTANT = 50 FT-LB/RAD.

NOZZLE HEIGHT ABOVE GROSS C.G., IN.	NOZZLE DEFLECTION, DEG.		
	3	6	9
2	A	B	B
3.75	C	C	C
5	C+	D	C
8	C	D	C-
11	C-	D	D
15	D-	D-	D-
	PILOT A	PILOT B	PILOT A

(a)

HIP SPRING CONSTANT = 50 FT-LB/RAD.
INERTIA OF LOWER BODY CORRESPONDING TO LEGS UP CONDITION

NOZZLE HEIGHT ABOVE GROSS C.G., IN.	NOZZLE DEFLECTION, DEG.		
	3	6	9
2	A	A	A
3.75	D+	C	C+
5	C+	C-	C
8	D	D	D
11	D-	D-	F
15	F	F	F
	PILOT B	PILOT A	PILOT B

(b)

Figure 32. Effect of Increased Hip Constant and Inertia of Lower Legs on Pilot Ratings

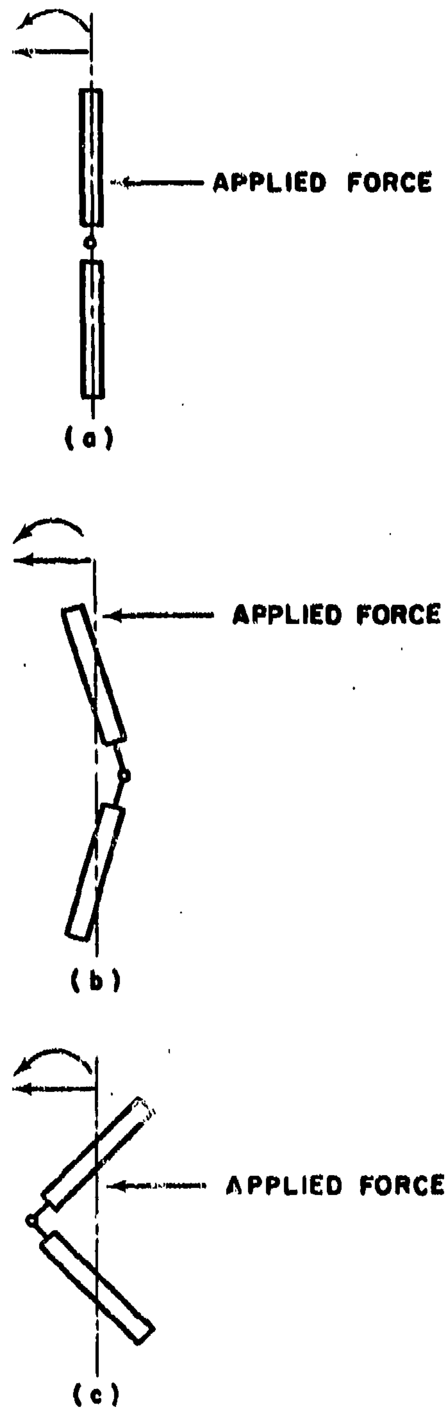


Figure 33. Illustration of Body Bending Mode Excitation

of secondary importance as a response stimulus. The pilots became more critical in their judgement as they became more proficient and began annotating plus (+) and minus (-) signs to the letter ratings. They repeated runs often and felt that with practice they could do better for the test runs in the D-F category.

C. CONCLUSIONS

From the results of the analog computer studies of the pilot-controlled lateral behavior of the SRLD the following conclusions can be made:

1. If stability augmentation is incorporated some damping should be present and low frequencies avoided. The overall studies do not show that stability augmentation is absolutely necessary.
2. The hip-spring constant has a primary influence on the system dynamics. High values are most desirable. Since it is a combined human-factor and physiological parameter its value is not accurately known.
3. Mass and inertia characteristics have noticeable effects on controlled behavior and further studies may prove valuable at a later date.
4. Control moments reduced from original design values resulted in highly improved handling characteristics.
5. The two-segment model exhibits some basic dynamic characteristics that make it suitable for analysis of SRLD configurations. Continued analysis may yield information valuable for kinesthetic control analysis.

D. RECOMMENDATIONS

Based on the overall test results it was recommended that the nozzle gimbal height of 2 inches above the gross c.g. be adopted along with 6 degree maximum nozzle deflection. These numbers would result in improved controlled lateral behavior characteristics.

IV. HUMAN FACTORS

Participation of Human Factors Personnel during Phase I, consisted chiefly in obtaining anthropometric data on the flight-test operator, proposing different possible control configurations, monitoring design of the SRLD feasibility model, providing body-mass data for REAC analog computer studies, and preparing flight plans for the SRLD Captive Flight-Test Program.

A. ANTHROPOMETRIC DATA

The anthropometric data presented in Table 2 were used in design of prototype equipment. Fitting of the fiberglass corset by means of a plaster-cast of the body was monitored by human factors and medical specialists. Emphasis was placed on supporting weight of the propellant-loaded SRLD device about the hips where severe injury is least likely to occur in a hard landing.

B. CONFIGURATIONS TO BE CONSIDERED

A hand controller-arm restraint design, which is relatively insensitive to acceleration forces, was proposed. Because of increased complexity over the existing design, the proposed concept was not incorporated in early test hardware. Unless simulator data and/or actual flight test indicate a need for reducing acceleration effects at the controller, this will not be incorporated during the program.

The following control system configurations were proposed for consideration in future design, or as specific alternatives to be included in the test program.

1. Pitch and roll control allocated to one hand, and throttle and yaw to the other. This would minimize the possibility of cross-coupling to be anticipated in a three-axis controller.

2. Kinesthetic control for pitch and roll, with a tiller or steering bar control for yaw. Yaw appears to be the control function most difficult to achieve by kinesthetic means and requires separate control. Steering and throttle control may then become a one-hand operation, freeing the other hand for other tasks.

TABLE 2

ANTHROPOMETRIC DATA RECORD

Name: Wendell Moore | Age: 42 | Date: 22 Aug 60

		Percentile			Percentile
Weight	147.5	24	Shoulder Breadth	18.0	55
Stature	69.5	57	Chest Breadth	11.5	25
Cervical Height	59.5	57	Waist Breadth	10.5	45
Shoulder Height	58.2	77	Hip Breadth	13.3	55
Suprasternale Height	56.5	53	Chest Depth	9.7	80
Waist Height	43.5	80	Waist Depth	9.7	96
Crotch Height	32.5	43	Neck Circumference	14.8	40
Sitting Height	-	-	Shoulder Circumference	43.5	23
Buttock-Leg Length	41.8	33	Chest Circumference	36.3	15
Span	69.5	33	Waist Circumference	32.5	60
Arm Reach	33.5	25	Buttock Circumference	-	-
Elbow to Elbow Breadth	17.0	45	Vertical Trunk Circumference	62.0	16
Hip Breadth	13.7	40			

3. Operator head motion for two or three-axis control. For example, control linkages could be fastened to head band or helmet, with forward head movement resulting in pitch forward to translate forward; the head moved to the right, would result in roll right, and translate right; rotating the head to the right or left would result in yaw.

One hand must necessarily be occupied with throttle control. It therefore seems probable that two-axis head control might be most desirable, with yaw and throttle control to be assigned to one hand as described above. Advantages of this system would include optimized control-response correlation, freedom of one hand for other tasks, and possible simplification of the control linkages.

C. BODY-MASS DATA

The Human Factors Section prepared body-mass distribution, center of gravity and spring rate data for use by the flight technology group in analog simulation studies.

After review of available literature, it was decided to use a regression equation developed by Barter, (see Reference 3) in determination of mass distribution data.

Center of gravity location in the separate body segments was derived by determining the over-all c.g. location of the test pilot experimentally, comparing it with average over-all c.g. location as determined by Dempster (see Reference 4) and using the resulting ratio to modify the body-segment c.g. locations as determined in the same reference.

Spring rate data for the human body, in the region of the abdomen and hip joint, was derived experimentally. The test pilot was suspended in a mock-up of the SRLD, and his upper body immobilized by fore, aft, and side tethers fastened at the waist. The force required to deflect the lower extremities in increments of five degrees was measured using a spring balance and large protractor. Measurements were taken in four directions -- fore and aft, and left and right. Spring rates were then calculated. Body segment weights used in the calculations were determined from the Barter regression equations. Observed and calculated data are presented in Table 3.

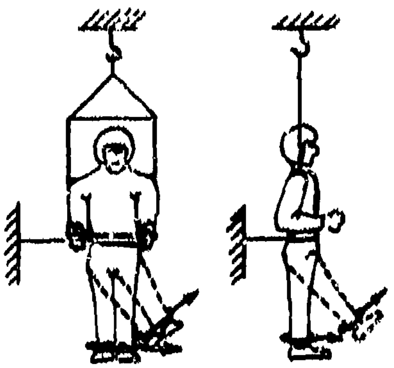
D. PREPARATION OF CAPTIVE FLIGHT-TEST PLANS

Flight-test plans were formulated with assistance from human-factors personnel in order to provide, as much as possible, for optimal conditions and sequences in learning to operate the SRLD, and to allow for these effects in evaluating alternative configuration.

TABLE 3

OBSERVED AND CALCULATED ANTHROPOMETRIC DATA

Parameters	Value	Remarks
Over-all length (supine), inch	70.5	-
Top of head to hip socket, inch	29.5	-
Knee to ankle, inch	16.75	-
Mass - total, lb	144.0	-
Upper body segment, lb	97.0	Determined using regression equations per Barter*
Lower extremities, lb	47.0	Determined using regression equations per Barter*
Center of Gravity - Over-all, inch	28.6	From top of head
Upper body segment	17.8	From top of head (determined using center of gravity locations as a percentage of segment length per Dempster**)
Thigh, inch	9.0	From hip joint**
Leg, inch	7.4	From knee joint**
Foot, inch	1.5	From ankle (estimated)



SPRING RATE DATA

Angle Degree	Tension in Pounds, Normal to Leg at Ankle: Side: Left	Right	Average	Fwd	Back
5	1.5	2.5	2.0	1.5	1.5
10	3.5	4.5	4.0	3.0	3.0
15	5.0	7.0	6.0	4.5	6.0
20	9.0	9.5	9.25	5.5	7.5
25	12.0	14.0	13.0	8.0	9.5
30	16.0	16.0	16.0	10.0	13.0

*Barter, reference 3
**Dempster, reference 4

E. LEARNING TO OPERATE THE SRLD

Two theoretical principles of learning were considered: (1) Simple-to-complex sequential progress and (2) whole-part practice.

A simple-to-complex sequence of SRLD tasks was thought be to an optimal plan for progressive skill acquisition by the SRLD flight operator. On a rational basis this was thought to be, perhaps, a progression from a simple hovering task to one requiring complex maneuvering. The flight plan was therefore established in this basis. However, further consideration of SRLD flight requirements has suggested that in actuality the hovering task may be the most difficult, and the plan may require revision on this basis.

The whole-part theory of practice in learning a complex motor skill was applied in recommended training and practice. For example, some combination of whole and part practice is employed and considered most effective in such motor skills as golfing, boxing, swimming, etc. In swimming, "whole" practice is accomplished by attempting the complete motor sequence, such as swimming across the pool. "Part" practice in the training-to-swim procedure is accomplished by practicing only the kick or the breathing rhythm.

The motor skill requirements in flying the SRLD, on a rational basis, would seem to involve such elements as proficiency in throttle, or vertical, control, yawing, pitching and rolling by such movements as those required of the arms, trunk, and legs, balancing and executing "kinesthetic" control for maneuvering. Further considerations are: muscle conditioning to bear the weight of the pack, adaptation to the clothing and required protective equipment, etc.

Several exploratory flights were proposed to provide the operator with such familiarization as might be described as "whole" practice. "Part"-type practice was accomplished and/or recommended as follows:

1. REAC analog computer tracking in the lateral and pitch axis.

2. REAC analog computer tracking in the vertical axis.

3. Adaptation and conditioning to personal equipment and the hip pack by exercises, similar to those required in flight, under dry-run conditions.

4. REAC analog computer coordinated control of vertical, pitch, yaw, and roll axes.

F. FLIGHT TEST PLANS

SRLD captive flight test plans were based on theoretical problems in learning to fly the SRLD, and on the tests and experimental controls necessary to evaluate the different possible SRLD flight control configurations.

Over-all flight test objectives in tethered flight were defined as follows:

1. Chiefly, to establish feasibility of control and flying qualities with optimal safety.

2. To establish the control configuration on the basis of performance criteria that are most proficiently controlled for free-flight tests.

Feasibility is to be largely established on the basis of general observations and flight operator opinion. The optimal control configuration will be determined on the basis of flight rating charts and quantitative analysis of film records.

The SRLD control system, proposed at this stage of the program, is to be provided with the following possible options to be tested:

1. "Kinesthetic" control, where a spherical pivot bearing at a center point to the shoulder harness is free to permit thrust diversion about the shoulders in pitch and roll. Locking is optional. (A pivot in the pitch axis has recently been discussed as unnecessary.)

2. "Automatic Roll Stabilization" with a left-hand stick, where linkages in roll actuate nozzles laterally, in pitch longitudinally, and in yaw, differentially in the longitudinal axis. Locking is optional for all axes, or any individual axis. (The automatic stabilization feature has been temporarily abandoned since the original thinking on this option. This was necessary due to the excessive weight that, it was determined, would be required for effective control.)

Table 4 lists the configurations in combinations of the above, and the flight tasks for performance evaluation.

The following order of flights were planned in order to control the biases that would otherwise be incurred from adaptation and learning. This is important, since the performance criteria with each configuration will be compared to select the optimal configuration for free flight tests. (The following Roman Numerals are also referred to in Table 4.

I. Hovering Control Tests - Ascend to five feet, maintain straight and steady attitude until timer signal occurs, descend and touch down.

Test 1 - Configuration A
Test 2 - Configuration B
Test 3 - Configuration C
Test 4 - Configuration D

II. Lateral Control Tests - Ascend five feet, translate right side to mark, return left to zero position, hover, and let down.

Test 5 - Configuration A
Test 6 - Configuration B
Test 7 - Configuration C or D*

III. Yaw-Right Control - Ascend to five feet, turn around right 360 degrees, hover, and let down.

Test 8 - Configuration E
Test 9 - Configuration C or D*

IV. Yaw-Left Tests - Ascend to five feet, turn around left 360 degrees, hover, and let down.

Test 10 - Configuration E
Test 11 - Configuration C or D*

V. Pitch Control Tests - Ascend to five feet, translate forward to mark, hover, and let down.

Test 12 - Configuration E
Test 13 - Configuration C or D*

VI. Combined Control - Ascend to five feet, translate forward to mark, turn around right 180 degrees, and translate forward to zero position, hover, and let down.

Test 14 - Configuration E
Test 15 - Configuration C
Test 16 - Configuration D

*This decision will be based on preliminary performance criteria in comparison of Tests 3 and 4.

TABLE 4

PLANNED SRLD TETHERED FLIGHT TESTS

Configuration	Flight Plan No.	Flight-Test Task
A. Kinesthetic	I	Hovering
	II	Lateral Control
B. Kinesthetic and Auto-Roll Stabilization	I	Hovering
	II	Lateral Control
C. Manual and Auto-Roll Stabilization	I	Hovering
	II	Lateral Control
	III	Yawing Right
	IV	Yawing Left
	V	Pitch Control
	VI	Combined Control
D. Kinesthetic, Manual and Auto-Roll Stabilization*	I	Hovering
	VI	Combined Control
E. Kinesthetic and Manual Yaw	III	Yawing Right
	IV	Yawing Left
	V	Pitch Control
	VI	Combined Control

*To be substituted for Configuration C, depending upon results in the hovering tasks. A free pivot, or kinesthetic control, may be essential in compensating for full center of gravity shift.

Recycle Tests

Test No.	Same as Test No.	Test No.	Same as Test No.
17	16	25	8
18	15	26	7
19	14	27	6
20	13	28	5
21	12	29	4**
22	11	30	3**
23	10	31	2**
24	9	32	1**

**Propellant duration time measures will be completed during these flights.

Preliminary evaluation criteria were established in the use of a flight rating chart by specialized observers and the flight operator himself, as well as flight analysis of film records following each flight.

Table 5 presents a flight rating chart to be used in the experimental evaluation.

Markings are provided on the flight operator's suit in order to facilitate interpretation and analysis of performance from film records. Figure 34 presents the front, side and rear flight suit markings to be employed.

Photographic records are expected to provide such performance data as follows:

a. Time to complete maneuvers

b. Accuracy of maneuvers

c. Damping rate

d. Translation rate

e. Ascent-descent rate

f. Interferring body and/or control motions.

TABLE 5

Test Date

SMALL ROCKET LIFT DEVICE FLIGHT RATING CHART
(Please check one number for each rating)

Test No.

	1 Excellent	2 Good	3 Satisfactory	4 Acceptable	5 Marginal	6 Unacceptable	7 Impossible	8 Hazardous	9 Dangerous	10 Killer
General Rating	Completely Confident	Easy to Control	Minor Difficulties in Control	Difficult to Control	Not much Confidence	Control Extremely Difficult	Cannot be Controlled	Injury Could Result	Operator Was Hurt	Fatal Injury May Result
Roll-or-Lateral Control Rating	Steady and Controlled		Oscillations Quickly Corrected and Trimmed		Oscillations Difficult to Control, Cannot Trim			Severe Oscillations Cannot Be Controlled		Oscillations and Direction Cannot be Controlled
Pitch or Fore-and-Aft Rating	Steady and Controlled		Moments Quickly Corrected and Trimmed		Moments Difficult to Control, Cannot Trim			Severe Moments and Oscillations Cannot be Controlled		Oscillation and Direction Cannot Be Controlled
Yaw Rating	Steady and Controlled		Spin Oscillations Quickly Corrected		Spin Difficult to Control			Spin Rate and Oscillations Cannot Be Controlled		Spin Oscillations and Direction Cannot Be Controlled
Control Cross-Coupling Rating	Uni-Directional and Steady		Some, But Easy to Control		Interference Difficult to Control			Interference Cannot Be Controlled		Sets Up Uncontrollable Omni-Directional Interference
Translation Control Rating	Accurate and Precise		Close and Adequate		Poor Control			Way Off Target		No Control Whatsoever
Body Control Rating	Easy Posture and Deliberate Movements		Body Somewhat Tense, But Control Easy		Disturbing Moments Induced. Posture Difficult to Control			Limbs Flail, Tense, No Control		No Control Whatsoever
Vertical Control Rating	Accurate and Precise Smooth Takeoff and Landing		Some fluctuation Easily Controlled		Difficult to Maintain, Takeoff and Landing Irregular			Cannot Be Controlled, Hard Takeoff and Landing		Control Impossible Takeoff and Landing Dangerous

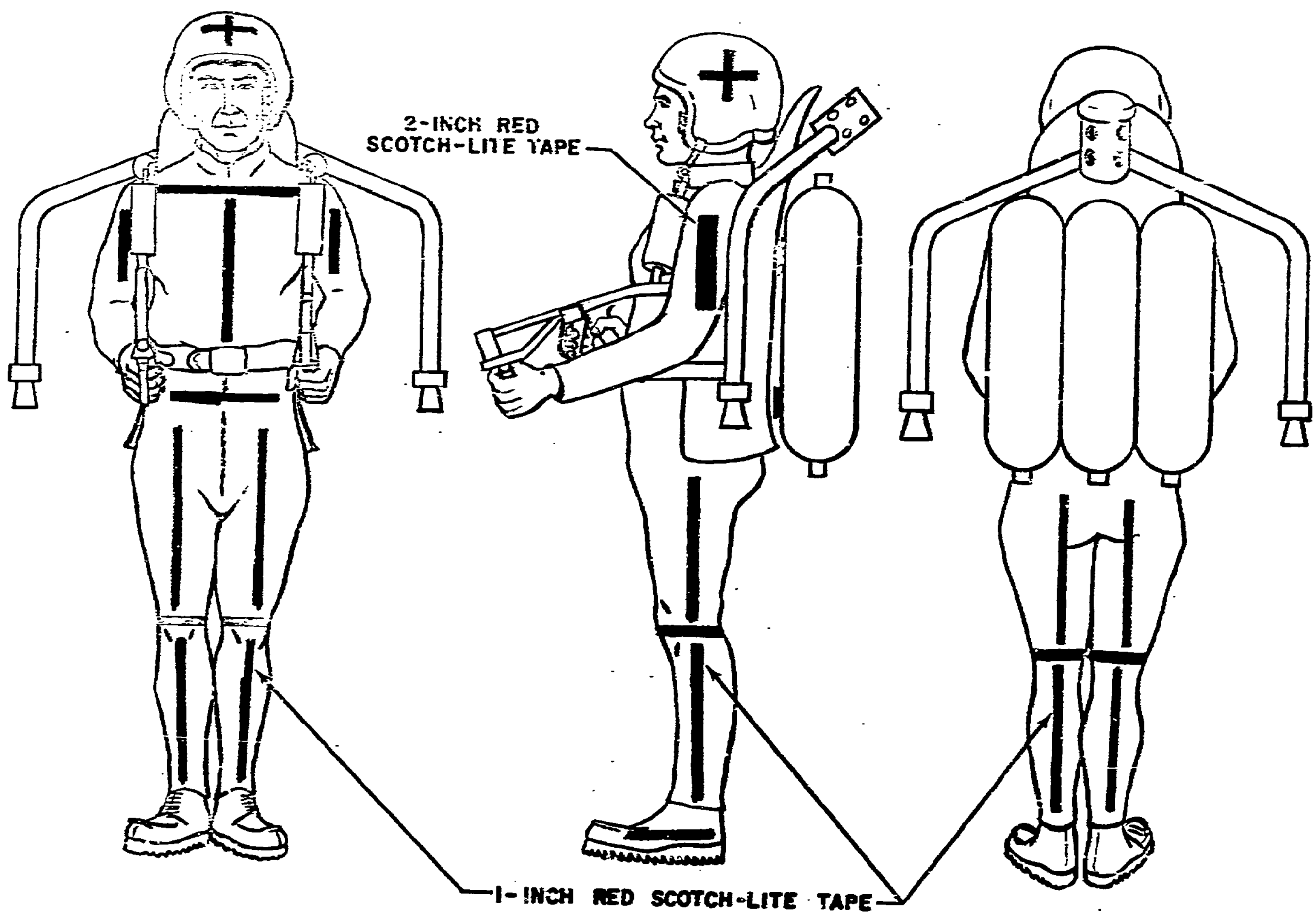


Figure 34. Flight Suit Striping

G. SUMMARY

Human Factors effort during the Phase I program has consisted largely in providing basic body-mass data, flight control analyses, and assisting in the preparation of a tethered-flight test plan. Flight-operator training requirements were also considered as part of the flight test program in order to develop control proficiency.

V. RELIABILITY

During the Phase I period, the reliability effort consisted of monitoring the testing of components for inclusion of reliability and safety objectives and analysis of the past history data on components used on the SRLD that have been utilized on other programs at Bell Aerosystems Company.

The components have been tested for performance parameters consistent with the SRLD design requirements. As highlighted elsewhere in this report, changes and/or modifications were made on components to meet the design requirements and to enhance the reliability and safety of the system by meeting or exceeding the system requirements. Although these components have successfully achieved the design requirements, only system level testing during Phase II will conclusively establish component safety margins because system failure definition in terms of component tolerances cannot be rigorously established at the component test level. Phase II will demonstrate the level of reliability achieved by the SRLD in tethered and free flights of the system.

Six components utilized on the SRLD have experienced various phases of testing during functional, system checkout, and system flights. These components are as follows:

1.	8060-472001	Manual Shutoff Valve
2.	8060-472004	Gas Filter
3.	62-472-088-1	Check Valve (Modified to 8123-472003)
4.	8060-472036	2-Way Selector Valve (Pressure and Vent Valve, (8123-472015)
5.	8060-472122	Relief Valve
6.	59-472-275-1	Fill and Drain Valve (8123-472005)

Table 6 presents a summary of the background data applicable to the SRLD program on each of these components and includes the computed and lower 90% confidence reliability when based on a 30-second flight of the SRLD.

1. 8060-472-001 — MANUAL SHUT-OFF VALVE

Eighty-six (86) units have been functionally tested and no failures were observed. During 527 hours of system testing, the manual shut-off valve was

TABLE 3

SUMMARY OF BACKGROUND DATA APPLICABLE TO SRLD PROGRAM

Component No.	Functional Test Phase		System Checkout Phases		Flight Phase		Computed 30 sec. Reliability for SRLD Program (3)	
	Number of Units Tested	Unit Rejection Rate	Component Operating Time	Observed Reliability	Component Operating Time	Observed Reliability	Computed	Lower 90% Confidence
8060-472001	86	0	527 hr.	0.9981/hr.	N/A	-	0.99998	0.99996
8060-472004-1	38	2.6%	705 hr.	0.9986/hr.	N/A	-	0.99999	0.99997
62-472-088-1	243	1.2%	212 hr.(1)	0.8438/hr.	8.4 hr.	1.00	0.99864	0.99830
8060-472036	13	7.7%	527 hr.	0.9981/hr.	N/A	-	0.99998	0.99996
8060-472122	17	0	270 hr.	1.0000/hr.	N/A	-	1.00000	0.99993
59-472-275-1	1614	1.3%	11275 hr.(2)	0.9999/hr.	42.1 hr.	1.00	0.99999	0.99999

(1) Two components used during 423 system checkouts averaging 2.5 hours of pressurization per checkout.

(2) Ten components used during 451 system checkouts averaging 2.5 hours of pressurization per checkout.

(3) System level testing during Phase II will conclusively establish component safety margins. System failure definition in terms of component tolerances cannot otherwise be rigorously established.

fail-free. Serial number 211 and 213 have been tested successfully for the SRLD. Based upon this data, this valve is computed to have a 30-second reliability of 0.99998 or 1 failure per 63,240 flights of the SRLD.

2. 8060-472-004-1 — GAS FILTER

Two discrepancies were experienced during the functional testing of 38 filters. One unit had a slight leakage at 3000 psig. Upon failure analysis, it was found that the teflon back-up ring was out of dimensional tolerance and this unit was returned to the vendor. Leakage at 4000 psig was also observed past the "O" ring on the second unit. However, the failure could not be duplicated, and the unit was successfully retested.

This filter has had extensive experience in a test cell as well as formal and informal PRFT testing. No system failures have been observed in 705 hours of operation.

The SRLD program has accepted filter numbers 205 and 206.

Based upon system data, this gas filter is computed to have a 30-second reliability of 0.99999 or 1 failure in 84,600 flights of the SRLD.

3. 8123-472-003-1 (62-472-088-1) — CHECK VALVE

This valve has had extensive experience in a previous program at Bell Aerosystems Company. Out of the 243 units functionally tested, only three units were rejected for failing the reverse flow requirements and were not acceptable for rework. Twenty-eight (28) units that failed during these tests were subsequently accepted after rework.

During system checkout, the dominant mode of failure experienced by this component was leakage. It was determined that 76 percent of these 38 leakages were caused by acid salt deposits from the oxidizer on the seat and poppet area. Since this oxidizer will not be used in the SRLD system, this mode of failure is considered to be of a much lower magnitude.

When this valve was used in actual flight, no failures were observed. Data from 2492 functional tests cycles, 423 system checkouts, and 101 flights of this component were analyzed and a summary of the results are presented below:

Observed reliability during flight (150 seconds)	1.00
Observed reliability during checkout (1 hour)	0.8438
Observed unit rejection rate during functional test	1.2%

The reliability of this check valve, when based on a 30-second flight, is computed to be 0.99864 or approximately 1 failure in 733 flights of the SRLD.

Serial numbers 1 and 2 have been acceptance-tested for the SRLD program. These valves are of the 8123-472-003-1 configuration which makes them compatible with H_2O_2.

4. 8060-472-036 – TWO-WAY SELECTOR VALVE (PRESSURE AND VENT VALVE)

Thirteen (13) units have been functionally tested to date and one failure was observed. This unit failed B/P Note #54, and allowed free flow past the push-pull spool. This unit was sent to rework to eliminate the scored seat at Port "C".

During system testing of this valve, the valve experienced 462 fail-free cycles in 527 hours of operation. Utilizing this system test data, this valve is computed to have a 30-second reliability of 0.99998 or 1 failure per 63,240 flights of the SRLD.

5. 8060-472-122 – RELIEF VALVE

This new valve has had no failures during the functional testing of seventeen (17) units tested to date.

This relief valve has performed successfully during 270 hours of system testing and when these data are applied to a 30-second flight of the SRLD, the computed reliability would be 100 percent. Since this valve is a safety component to prevent system rupture in the event some impurities are accidentally introduced into the system, this 100 percent flight reliability will continue. This is based on the fact that over-pressurization will be evident prior to flight, therefore, the flight will be aborted and action taken to eliminate the abnormal situation.

6. 59-472-275-1 – FILL AND DRAIN VALVE (8123-472005)

Data from December 1953 to date has been analyzed on this fill and drain valve. A total of 1614 units have been functionally tested and experienced 101 failures. However, only 21 units were rejected with the balance of the units being accepted after rework.

During system checkout, one failure was observed. A deposit of acid salts on the seat and poppet area had allowed leakage of the oxidizer. Since

this oxidizer will not be used in the SRLD system, this type of failure will not exist. No failures were observed when this valve was in flight.

Data from 3283 functional test cycles, 451 system checkouts, and 101 flights of this component were analyzed and a summary of the results are presented below.

Observed reliability during flight (150 seconds)	1.00
Observed reliability during checkout (1 hour)	0.99078
Observed unit rejection rate during functional test	1.3%

The reliability of this fill and drain valve during system checkout, when based on a 30-second flight, is computed to be 0.99996 or approximately 1 failure in 25,000 flights of the SRLD.

During Phase I, the gas generator was tested for performance, reliability, and safety. One hundred and one tests were conducted on the gas generator with no performance degradation in 3070 seconds of operation. Performance parameters have displayed a consistent ±1% repeatability and no safety hazards were evident. Since the gas generator is a direct outgrowth of the present gas generators used on other programs, it is evident that the high degree of reliability necessary for this man-rated system has been achieved.

The throttle control valves and rocket nozzles have been modified to meet the design requirements at the component test level. Due to the time delay in the modification of the throttle control valve, the scheduled 500 cycle reliability test was not accomplished in Phase I. Any "unreliable factors" in these components are a function of mechanical tolerances in the successful performance of their operation. The design of these components has been orientated towards minimizing critical tolerances to enhance reliability. Any additional features that become evident in subsequent flight during Phase II will be incorporated.

Since the proposed regulator did not meet the design requirements, a modified Grove 94X Mitey-Mite regulator was chosen as a substitute. This regulator was tested to obtain regulation and flow characteristics of the regulator under various cycle and flow tests and to establish a confidence level of reliability. Although the regulator had dropped 10 psi below the initial setting after 250 cycles, this is not considered significant and this regulator is adequate for SRLD use. Based upon the data of this test, there is 90 percent confidence that the regulator would not have more than one failure in 110 flights of the SRLD. The best estimate, which is less pessimistic, has a reliability of no more than one failure in 175 flights.

The AN6025HX416-21 compressed gas cylinder is an ICC-approved item and past history throughout the industry has indicated a high level of reliability.

Cycle, proof, and burst tests were conducted on the H_2O_2 tank assembly for performance parameters and for reliability and safety factors. After 2000 successful cycles, the tanks were tested for a burst pressure. At 1150 psi, a crack developed at the lower left hand weld area and testing was terminated. This 2.2 relief valve-to-burst factor is considered to be a sufficient safety margin for the SRLD design.

The gages and hi-pressure fill valve have met the design requirements of the SRLD. Bell Aerosystems Company does not have detailed experience data on these components, although they are accepted by industry for their performance parameters and reliability.

Based upon past experience and Phase I testing, it is felt that the SRLD can achieve the high degree of reliability necessary for this man-rated system. The actual level of reliability that can be demonstrated will be a function of the flights made during Phase II.

VI. REFERENCES

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Appendix I. Compatibility of Polyvinyl Chloride Rubber with 90% Hydrogen Peroxide

A. GENERAL

The following results are applicable for both vinyl rubbers submitted for test. The materials are:

1. Rubatex R-310V

2. Ensolite, U. S. Rubber

B. MATERIAL COMPATIBILITY

The vinyl rubbers were immersed in 90% hydrogen peroxide with no immediate reaction upon contact. After a 5-minute retention period, several bubbles were slowly forming on the surface of the materials. This process proceeded for 24 hours and then the samples were removed from the peroxide. At no time was there noted any vigorous evolution of gas.

The vinyl rubbers retained most of their resiliency, but suffered a marked decrease in tensile strength. They swelled to approximately 150% of their original volume. The color was bleached from tan to light tan, approaching white.

C. SHOCK SENSITIVITY

The apparatus used to determine the following data was an Olin-Mathieson Impact Sensitivity Tester. The information reported are average values of numerous drop tests.

	Rubbers Subjected to:	Impact Sensitivity Inch-Ounces	Comments
1.	Virgin	6992	Very stable to shock.
2.	Overnight soak in 90% H_2O_2, squeezed dry, test run.	5520	Quite stable to shock.
3.	Overnight soak in 90% H_2O_2, soaked in water for 10 min., squeezed dry, test run.	6256	Very stable to shock.
4.	Overnight soak in 90% H_2O_2, soaked in water for 10 min., air dried for 24 hrs., test run.	4600	Not as stable to shock as above.
5.	Same as (4), except dried @ 122°F for 24 hrs., test run.	3220	Approaching the lower limits of shock stability.
6.	TNT	2000	As a comparison, quite shock sensitive.

C. <u>SHOCK SENSITIVITY</u> (Cont'd)

Rubbers Subjected to:		Impact Sensitivity Inch-Ounces	Comments
7.	RDX	1340	Quite shock sensitive.
8.	Lead Azide	720	Very shock sensitive.

At no time were explosions encountered during the above tests, but definite discoloration of the materials warrants that they be classified as shock sensitive for that particular situation.

Appendix II. SRLD System Distilled Water Flow Tests

ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 7

Test Item SN 1 Test No. LD-91 Test Item SRLD

Date Work Order 6876-000

Test Engineer L. Sileo Test Facility W-1

TEST:

SRLD System Distilled Water Flow Tests.

PURPOSE:

To evaluate the nitrogen pressurisation and propellant tank systems in regard to available nitrogen and usable propellants.

REMARKS:

See attached sheets.

DATA RECORDED ON: Speedomax

Test No. 1

1. The tanks were filled with distilled H_2O up to the point of tangency between cylinder portions and domes using approximately 30 psig pressure. The time required to fill the tanks was 7 min/45 sec.

2. The N_2 bottle was charged to 2000 psig. Leaks were noted at the inlet port of the shutoff valve and at the "O" ring under the schrader valve. The tests were run without sealing these leaks.

3. The 94 X dome pressure was vented.

4. The pressure and vent valve was placed in the pressurize position.

5. The N_2 shutoff valve was opened.

6. The 94 X dome was adjusted to provide a propellant tank static pressure of 450 psig. The nitrogen system was recharged to 2100 psig.

7. The system was flowed until the first indication of gas at the outlet was noted. The hand valve (throttle valve not available), was shut off as soon as possible. The propellant tank pressure dropped to 430 psig during the run. Thirty pounds of water were discharged during the run. The source pressure prior to the run was 1900 psig. After the run the source pressure was 950 psig. The maximum flow was 1.40 lbs/sec of H_2O.

8. The tanks were vented by means of the pressure and vent valve.

9. The tanks were drained and found to contain a residual of 1.5 pounds of H_2O.

Test No. 2

1. The tanks were filled with distilled H_2O up to the point of tangency between cylinder portions and domes using approximately 30 psig pressure.

2. The N_2 bottle was charged to 2100 psig.

3. The pressure and vent valve was placed in the pressurize position.

4. The N_2 shutoff valve was opened at the rate of approximately 90° (full open) in one second and the tank pressure rose in a gradual manner with no overshoot noted on the tank pressure gage. The tank pressure was 450 psig.

5. The system was flowed at full open until the first indication of gas at the outlet. The hand valve was shut off as soon as possible. Thirty-three and a quarter pounds of H_2O were discharged. The source pressure prior to the run was 1900 psig. After the run the source pressure was 700 psig. The maximum flow was 1.92 pounds of H_2O/sec., and was maintained for a total of 17.2 seconds.

6. The tanks were vented by means of the pressure and vent valve.

7. The tank contained no residual water.

Test No. 3

1. The tanks were filled with distilled H_2O up to a level of one inch above the dome tangency point, using approximately 30 psig.

2. The N_2 bottle was charged to 2150 psig.

3. The pressure and vent valve was placed in the pressurize position.

4. The N_2 shutoff valve was opened at the rate of approximately 90° (full open) in one second and the tank pressure rose in a gradual manner with no overshoot noted on the tank pressure gage. The tank pressure was 450 psig.

5. The system was flowed at full open, until the first indication of gas at the outlet. The hand valve was shut off as soon as possible. The propellant tank pressure dropped to 410 psig during the run. Thirty-four and a quarter pounds of H_2O were discharged. The source pressure prior to the run was 2000 psig. After the run the source pressure was 750 psig. The gage downstream of the orifice was recording a pressure of 170 psig. The maximum flow was 1.89 lbs/sec and was maintained for 17.4 seconds.

6. The tanks were vented by means of the pressure and vent valve.

7. The tanks contained no residual water.

Test No. 4

1. The tanks were filled with distilled water up to a level of one inch above the dome tangency point using approximately 30 psig.

2. The N_2 bottle was charged to 2100 psig.

3. The pressure and vent valve was placed in the "vent" position.

4. The N_2 shutoff valve was opened.

5. The pressure and vent valve was put in the pressurize position. The propellant tank N_2 pressure rose in a gradual manner (slow rise), with no overshoot noted on the tank pressure gage to a pressure of 450 psig. However, the regulator did not hold this pressure but allowed the tank pressure to very slowly creep up to 510 psig. The source pressure dropped to 1875 psig.

6. The pressure and vent valve was placed in the vent position. A little H_2O vapor was noticed leaving the vent line.

7. The pressure and vent valve was placed in the pressurize position. The propellant tank N_2 pressure was 450 psig. The source pressure dropped to 1775 psig.

   The pressure and vent valve was placed in the vent position. A little H_2O vapor was noticed leaving the vent line.

8. The pressure and vent valve was placed in the pressurize position and the system was flowed until about 22% of the original tank water was still in the tanks. At this point the shutoff valve was closed. Twenty-six and three quarter pounds of water were discharged. The source pressure prior to the water flow was 1775 psig. The source pressure after the water flow was 900 psig.

9. The tanks were vented by using the pressure and vent valve.

10. The system was repressurized with the remaining source pressure of 900 psig. There was no rise in static regulated tank pressure noted because the source pressure and the tank pressure were both equal to 290 psig.

11. The hand valve was opened and the entire system allowed to deplete itself of water and nitrogen. The propellant tanks contained 34 pounds of water when they were filled for this run.

Test No. 5

1. The N_2 bottle was charged to 2100 psig.

2. The propellant tanks were filled with distilled water up to a level of one inch above the dome tangency point using approximately 30 psig.

3. The pressure and vent valve was placed in the pressurize position.

4. The N_2 shutoff valve was opened.

5. The dome pressure of the 94 X regulator was raised until the relief valve opened. This pressure was 600 psig. The N_2 shutoff valve was shut off.

6. The N_2 shutoff valve was opened and the relief valve was opened a few more times. The opening pressure remained at 600 psig. This valve was subsequently reset so that for 3 cycling operations it opened at 530 psig, and reseated at 465-480 psig.

Test No.	N_2 Bottle Charge Pressure	N_2 Bottle Pressure After Flow	Total Flow H_2O (Lbs.)	Residual H_2O (Lbs.)	Tank Pressure	Dynamic Tank Pressure
1	2100	950	31-1/2	1-1/2	450	430
2	2100	700	33-1/4	0	450	-
3	2150	750	34-1/4	0	450	410
4	2100	900	34	0	510	-
4	-	-	-	-	450	-
4	-	-	-	-	290	-

Test No.	N_2 Bottle Charge Pressure For Flow	Pressure Downstream of Orifice	Maximum Actual Flow Lbs/Sec	Length of Run at Maximum Flow in Seconds
1	2100	-	1.40	-
2	1900	-	1.92	17.2
3	2000	170	1.89	17.4
4	1875	-	0.40	-
4	1775	-	-	-
4	290	-	-	-

Table III-1. SRLD System Water Flow Tests - Data Summary.

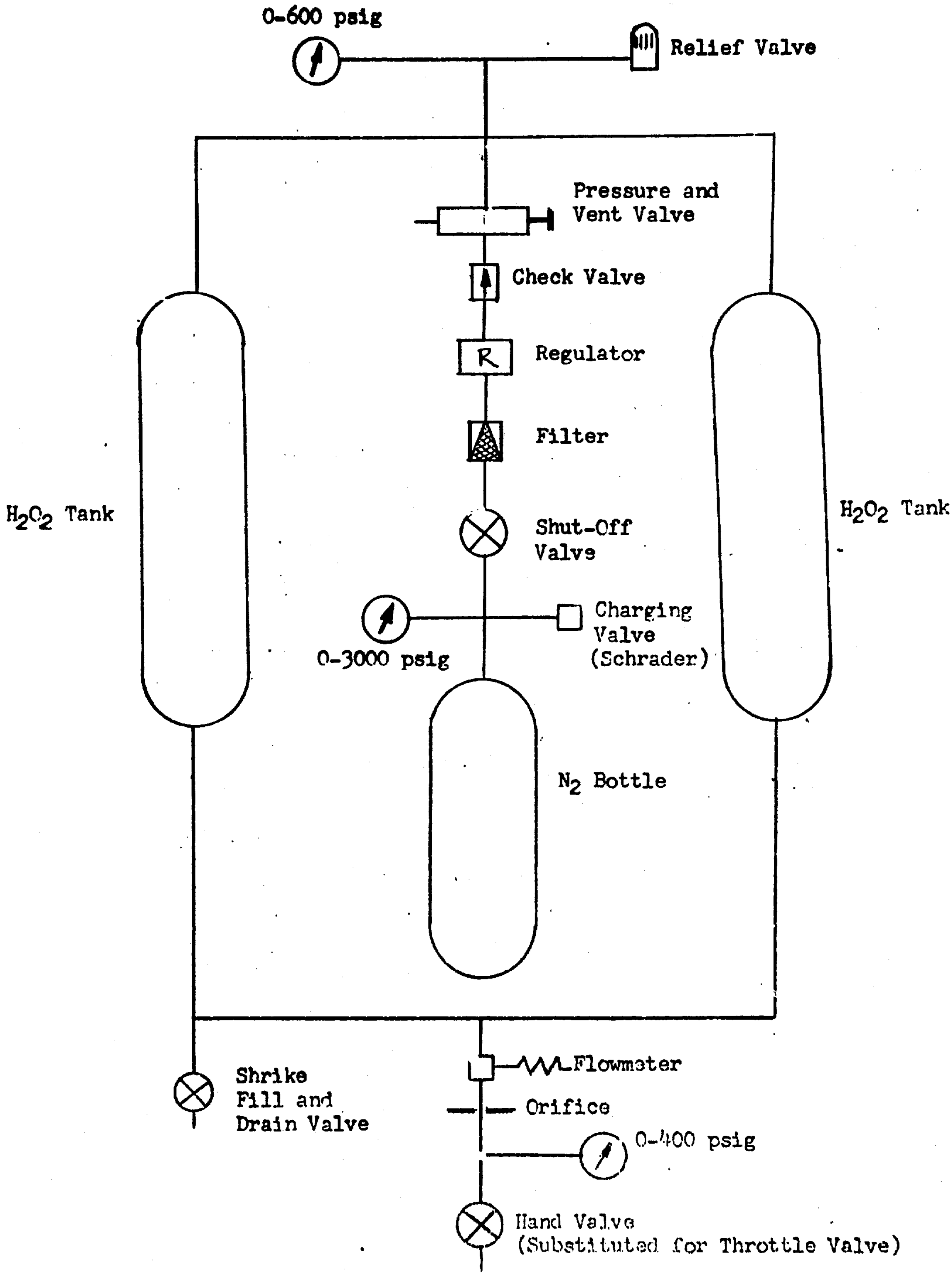


Figure III-1. Schematic Diagram - SRLD System Distilled Water Flow Test Setup.

Appendix III. Nitrogen Pressure Regulator

ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 4

Test Item SN	Test No. 81232-1-3	Test Item	SRLD
Date	November 24, 1960	Work Order	6876-000
Test Engineer	J. LaSpisa	Test Facility	Cell D-6A

TEST:

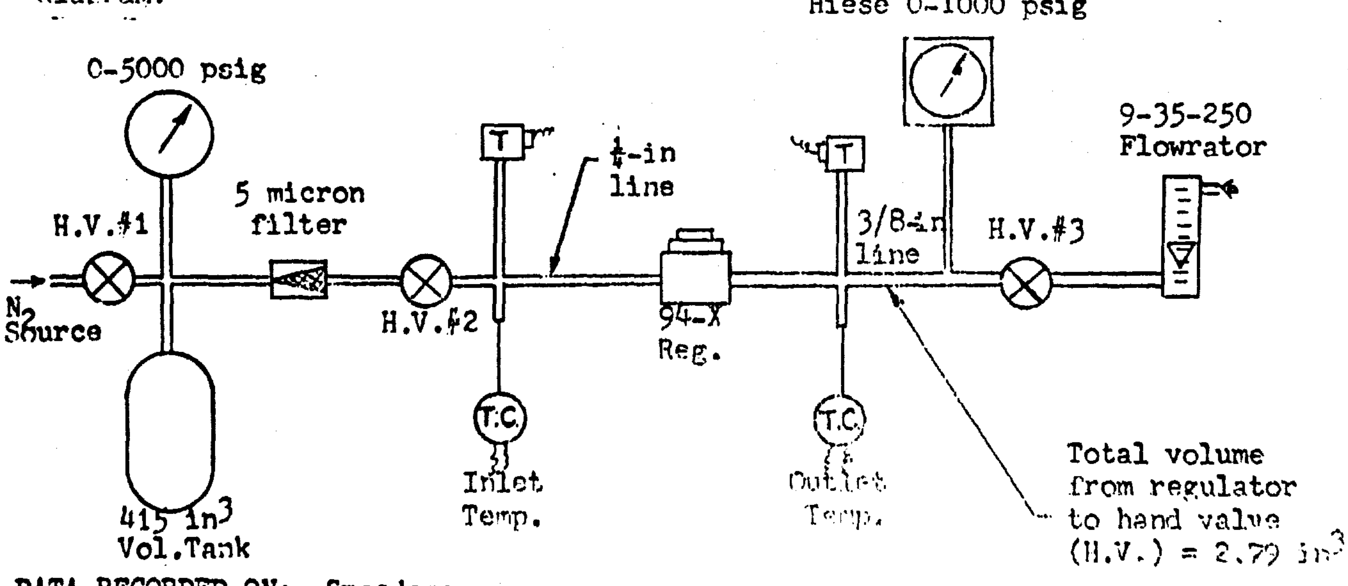
Flowing of the Grove 94X Mity-Mite Regulator, reworked to RLO 8123-005, per LTR 60-R-33.

PURPOSE:

To obtain regulation and flow characteristics of the regulator under various cycle and flow tests and to establish a confidence level of reliability.

PROCEDURE:

The regulator was installed in a test system as represented in the following diagram:



DATA RECORDED ON: Speedomax

The regulator was tested in the following sequence:

1. The regulator was adjusted to 457 psig pressure in a dead ended condition.

2. A seat leakage test was conducted for 30 minutes at an inlet pressure of 2150 psig and the outlet pressure dead ended in a 2.79 in^3 volume. A Hiese gage was used to monitor outlet pressure and gas temperature was monitored with thermocouples.

3. The seat leakage was repeated at an inlet pressure of 850 psig.

4. The regulator was cycled 250 times by opening and closing hand valve #3 to flow 42 scfm at each cycle. At each 25 cycles, the following parameters were recorded.

   a. Source pressure, regulated pressure and temperatures at dead ended conditions.
   b. Source pressure, regulated pressure and temperatures while flowing 42 scfm of N_2 gas.
   c. Source pressure, regulated pressure and temperatures while flowing 62 scfm of N_2 gas.
   d. Source pressure, regulated pressure and temperatures at dead ended conditions.

   At no time during the 250 cycle test, was the source pressure in the 415 in^3 tank, allowed to decay below 800 psig.

5. Steps numbers 2 and 3 were repeated.

DATA AND RESULTS:

Leak test at 2150 psig.

Elapsed Time (min)	Source Pressure (psig)	Regulator Pressure (psig)	Temperature (°F)
0	2150	456	57°
15	2150	456	57°
30	2150	456	57°

Leak test at 850 psig.

Elapsed Time (min)	Source Pressure (psig)	Regulator Pressure (psig)	Temperature (°F)
0	850	459	64°
15	850	460	68°
30	850	460	68°

Cycle No.	Source Press. No Flow	Reg. Press. No Flow	Temp. °F In	Temp. °F Out	Source Press. at 42 scfm	Reg. Press. at 42 scfm	Temp. °F In	Temp. °F Out	Source Press. at 62 scfm	Reg. Press. at 62 scfm	Temp. °F In	Temp. °F Out	Source Press. at 42 scfm	Reg. Press. at 42 scfm	Source Press. No Flow	Reg. Press. No Flow	Temp. °F In	Temp. °F Out
1	2150	460	70	70														
25	2110	457	66	67	1800	447	68	57	1360	444	64	57	1400	449	1475	458	64	57
50	1900	460	69	69	1620	452	68	60	1120	447	57	55	1175	455	1250	462	59	57
75	2100	458	62	62	1700	448	58	50	1230	443	64	53	1270	450	1330	459	58	53
100	1980	453	57	59	1650	444	58	45	1120	440	62	49	1150	446	1220	455	59	58
125	1900	448	51	55	1600	438	51	48	1175	434	59	41	1200	440	1285	450	56	46
150	2040	450	60	58	1700	442	59	45	1280	437	66	50	1275	443	1380	452	65	62
175	2090	451	63	60	1750	443	63	47	1285	438	66	50	1320	446	1390	453	61	50
200	2010	450	58	55	1680	441	56	41	1150	437	66	48	1200	443	1270	452	59	49
225	2090	448	54	51	1700	438	50	37	1100	433	66	48	1200	441	1260	450	60	48
250	2040	448	55	52	1680	439	51	38	1115	433	66	47	1240	445	1320	450	60	47

250 Cycle Test

Leak Test at 2150 psig.

Elapsed Time (min)	Source Pressure (psig)	Regulator Pressure (psig)	Temperature (°F)
0	2150	451	70°
15	2150	455	71°
30	2150	457	73°

Leak Test at 850 psig.

Elapsed Time (min)	Source Pressure (psig)	Regulator Pressure (psig)	Temperature (°F)
0	850	457	68°
15	850	461	72°
30	850	463	72°

SUMMARY AND CONCLUSIONS:

Tank capacity of the 415 in^3 source tank was sufficient to run 25 cycles plus one cycle into instruments. The tank was repressurized after every 25 cycles.

Regulated pressure dropped about 10 psi during flow at 42 scfm as compared to dead ended pressure. It dropped another 5 psi while flowing 62 scfm. At the end of 250 cycles, the regulated pressure had dropped to 450 psig, which is 10 psi lower than the setting at the first cycle. This pressure is the minimum setting requested in the L.T.R.. The lowest pressure recorded during flow, was 433 psig at 625 scfm. This drop, of 17 psi from the minimum 450 psig setting, was considered tolerable by the Small Rocket Lift Device Engineers.

Gas temperature, at the outlet of the regulator dropped an average 10°F during flow at each recorded cycle.

The summary of the data, shows that this regulator should be satisfactory for use in the Small Rocket Lift Device.

ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 2

Test Item SN 1 Test No. LD-1 thru LD- - Test Item SRLD

Date October 14, 1960 Work Order 2228-025

Test Engineer F. A. Urbaniak Test Facility W-1

TEST:

Gas Generator

PURPOSE:

Conditioning of catalyst bed.

REMARKS:

Test unit ran seven seconds of a scheduled 30-second run. Test was discontinued because the nozzles shifted, causing the steam to miss the exhaust ducts; consequently, filling the test cell with steam. Nozzle shift was due to the mounting bracket not being stiff enough. This is being corrected.

Examination of the data disclosed that the unit did not reach stability.

DATA RECORDED ON: Speedomax

CELL W-1 Sheet 2 of 2

At = .7040 in^2 Test No. LD- 1 to LD- -

TEST NO.	LD-1		LD-		LD-		LD-		LD-	
DURATION sec	7.0									
ΣDURATION sec	7.0									
TIME OF DATA	Static	6.5	Static		Static		Static		Static	
LNP psig		268								
RNP psig		268								
OCP psig		278								
FLP psig		350								
LP psig	459	320								
TP psig	461	419								
ΔP psi		33.8								
W lb/sec		2.25								
LNT °F		1312								
RNT °F		Off scale								
OCT °F		726								
FLT °F										
PFT °F										
EXT °F										
BT °F										
Ts_1 °F	74	641								
Ts_2 °F	72	624								
Ts_3 °F	71	528								
C* ft/sec										
F lb										
Isp sec										
W_{corr} lb/sec										
F_{corr} lb										
Pc Abs Corr										

ROCKET LABORATORY PRELIMINARY TEST REPORT

Test Item SN 1 Test No. LD-2 thru LD-9 Test Item SRLD

Date October 17, 1960 Work Order 2228-025

Test Engineer F. A. Urbaniak Test Facility W-1

TEST:

Gas Generator

PURPOSE:

Catalyst bed conditioning and initial gas generator assembly reliability runs.

REMARKS:

LD-2 and -3 were made to condition the catalyst bed and determine the proper tank pressure to set before the runs.

LD-4 through -9 were a series of 30-second runs maintaining a gas generator pressure of 285 psig.

DATA RECORDED ON: Speedomax

At = .7040 in^2 Test No. LD-2 to LD-6

TEST NO.	LD-2		LD-3		LD-4		LD-5		LD-6	
DURATION sec	18.5		28.5		30.0		30.7		30.2	
ΣDURATION sec	22.5		54.0		84.0		114.7		144.9	
TIME OF DATA	Static	18.0	Static	28.0	Static	29.5	Static	30.2	Static	29.7
LNP psig		264		269		277		274		269
RNP psig		264		270		278		273		269
OGP psig		273		277		284		282		277
FLP psig		350		369		382		380		378
LP psig	452	369	477	389	496	402	495	404	489	399
TP psig	456	418	478	439	501	459	498	454	490	450
ΔP psi		30.9		32.6		33.6		32.6		31.8
W lb/sec		215		221		2.24		2.21		2.19
LNT °F		1560		1371		1382		1370		1381
RNT °F		1382		1391		1341		1380		1376
OGT °F		erratic		1124		1216		1289		1230
FLT °F										
PFT °F										
EXT °F										
BT °F										
Ts_1 °F		off scale		1253		1242		1260		1287
Ts_2 °F		1149		1100		1097		1123		1160
Ts_3 °F		off scale		[illegible]		1304		1309		1303
C* ft/sec						2960		2959		2940
F lb						273.9		270.1		265.9
Isp sec						122.3		122.2		121.4
W_{corr} lb/sec						2.35		2.32		2.31
F_{corr} lb						287.0		284.2		280.9
Fc Abs Corr.						306.5		303.5		300.0

A_t = .7040 in^2 Test No. LD-7 to LD-9

TEST NO.	LD-7		LD-8		LD-9		LD-		LD-	
DURATION sec	30.0		30.2		30.0					
ΣDURATION sec	174.9		205.1		235.1					
TIME OF DATA	Static	29.5	Static	29.7	Static	29.5	Static		Static	
LNP psig		273		275		276				
RNP psig		273		276		277				
OOP psig		281		282		285				
FLP psig		382		384		387				
LP psig	494	402	497	403	503	408				
TP psig	495	455	504	460	507	463				
ΔP psi		32.7		33.5		33.7				
W lb/sec		2.22		2.24		2.25				
LNT °F		1379		1365		1356				
RNT °F		1368		1367		1384				
OOT °F		1390		1379		1392				
FLT °F										
PFT °F										
EXT °F										
BT °F										
Ts_1 °F		1267		1277		1236				
Ts_2 °F		1185		1171		1166				
Ts_3 °F		1291		1284		1270				
C* ft/sec		2941		2940		2937				
F lb		269.7		272.0		272.9				
Isp sec		121.5		121.4		121.3				
W_{corr} lb/sec		2.33		2.34		2.34				
F_{corr} lb		282.8		284.2		283.7				
Pc Abs Corr		302.0		303.5		303.0				

ROCKET LABORATORY PRELIMINARY TEST REPORT

Test Item SN	1 Test No. LD-10 thru LD-12	Test Item	SRLD
Date	October 18, 1960	Work Order	2228-025
Test Engineer	F. A. Urbaniak	Test Facility	W-1

TEST:

Gas Generator

PURPOSE:

Reliability Testing of Gas Generator Assembly

REMARKS:

Runs LD-10 and 11 were made maintaining a gas generator pressure of 285 psig. From Run LD-12 on, chamber pressure will be defined by Nozzle Pressure.

All three runs were smooth and were of 30-second duration each.

DATA RECORDED ON: Speedomax

CELL W-1 Sheet 2 of 2

At = .7040 in^2 Test No. LD-10 to LD-12

TEST NO.	LD-10		LD-11		LD-12		LD-		LD-	
DURATION sec	30.5		29.9		30.7					
ΣDURATION sec	265.6		295.5		326.2					
TIME OF DATA	Static	30.0	Static	29.4	Static	30.2	Static		Static	
LNP psig		272		273		279				
RNP psig		272		274		279				
OOP psig		279		279		286				
FLP psig		383		385		395				
LP psig	458	403	499	404	514	417				
TP psig	502	458	505	461	517	471				
ΔP psi		32.8		32.8		34.1				
W lb/sec		2.22		2.22		2.26				
LNT °F		1350		1352		1349				
RNT °F		1356		1358		1356				
OOT °F		1362		1365		1366				
FLT °F										
PFT °F										
EXT °F										
FT °F										
T_{S1} °F		1244		1235		1260				
T_{S2} °F		1157		1181		1238				
T_{S3} °F		1261		1260		1270				
C* ft/sec		2931		2946		2942				
F lb		268.7		270.1		275.3				
Isp sec		121.0		121.7		121.8				
W corr lb/sec		2.32		2.22		2.32				
F corr lb		281.4		[illegible]		[illegible]				
F @ At corr		[illegible]		301.0		301.5				

ROCKET LABORATORY PRELIMINARY TEST REPORT

Test Item SN	1 Test No. LD-13 thru LD-17	Test Item	SRLD
Date	October 18, 1960	Work Order	2228-025
Test Engineer	H. M. Graham, 2nd Shift	Test Facility	W-1

TEST:

30-second full thrust firings on the gas generator

PURPOSE:

To determine the reliability of the gas generator assembly.

REMARKS:

No noticeable drop in nozzle pressure was recorded.

DATA RECORDED ON: Speedomax

At = .7040 in^2 Test No. LD-13 to LD-17

TEST NO.	LD-13		LD-14		LD-15		LD-16		LD-17	
DURATION sec	30.2		30.2		29.8		30.6		30.0	
ΣDURATION sec	356.4		386.6		416.4		447.0		477.0	
TIME OF DATA	Static	29.7	Static	29.7	Static	29.3	Static	30.1	Static	29.5
LNP psig		279		282		286		285		286
RNP psig		281		283		287		285		285
GOP psig		288		291		294		292		294
FLP psig		396		403		408		407		408
LP psig	515	421	522	426	533	432	529	428	533	429
TP psig	522	478	520	480	536	488	535	487	536	488
ΔP psi		34.1		35.0		35.7		35.7		35.7
W lb/sec		2.26		2.28		2.31		2.31		2.30
LNT °F		1348		1354		1352		1352		1367
RNT °F		1358		1365		1360		1361		1358
GGT °F		1384		1359		1355		1358		1355
FLT °F										
PFT °F										
EXT °F										
BT °F										
Ts_1 °F		1267		1268		1265		1266		1275
Ts_2 °F		1222		1234		1208		1211		1222
Ts_3 °F		1276		1277		1291		1278		1270
C* ft/sec		2959		2958		2959		2944		2962
F lb		276.2		278.5		282.3		280.9		281.4
Isp sec		122.2		122.2		122.2		121.6		122.3
W_{corr} lb/sec		2.31		2.31		2.32		2.32		2.31
F_{corr} lb		282.8		281.8		283.2		282.3		282.3
Pc Abs Corr		302.0		301.[illegible]		302.5		301.5		301.5

ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 2

Test Item S/N 1 Test No. LD- 18 thru LD- 22 Test Item SRLD

Date October 19, 1960 Work Order 2228-025

Test Engineer F. A. Urbaniak Test Facility W-1

TEST:

Gas Generator

PURPOSE:

Reliability testing of gas generator assembly.

REMARKS:

These runs were of 30 seconds each. All were smooth and a preliminary look at the data indicates that the values are in the range expected.

On Run LD-22 the noise level at approximately the location at the pilot's head was checked by a meter to be 131 db.

DATA RECORDED ON: Speedomax

At = .7040 in^2 Test No. LD- 18 to LD- 22

TEST NO.	LD- 18		LD- 19		LD- 20		LD- 21		LD- 22	
DURATION sec	30.5		29.7		29.9		29.9		29.4	
ΣDURATION sec	507.5		537.2		567.1		597.0		626.4	
TIME OF DATA	Static	30.0	Static	29.2	Static	29.4	Static	29.4	Static	28.9
LNP psig		285		288		288		286		288
RNP psig		285		288		289		286		288
OOP psig		292		295		297		294		295
FLP psig		408		410		414		410		412
LP psig	529	429	537	435	540	437	534	432	540	436
TP psig	537	494	541	494	543	493	536	490	541	490
ΔP psi		35.5		36.0		36.9		36.1		35.9
W lb/sec		2.30		2.32		2.35		2.32		2.32
LNT °F		1364		1346		1353		1353		1355
RNT °F		1356		1355		1350		1356		1372
OOT °F		1364		1364		1371		1379		1400
FLT °F										
PFT °F										
EXT °F										
BT °F										
Ts_1 °F		1320		1266		1267		1257		1239
Ts_2 °F		1209		1212		1230		1224		1241
Ts_3 °F		1260		1256		1266		1261		1271
C* ft/sec		2957		2961		2928		2941		2961
F lb		280.9		283.7		284.2		281.8		283.7
Isp sec		122.1		122.3		120.9		121.5		122.3
W_{corr} lb/sec		2.31		2.32		2.33		2.32		2.31
F_{corr} lb		281.8		283.7		282.3		281.8		282.8
Pc Abs Corr		301.0		303.0		301.5		301.0		302.0

ROCKET LABORATORY PRELIMINARY TEST REPORT

Test Item SN 1 Test No. LD- 23 thru LD- 27 Test Item SRLD

Date October 19, 1960 Work Order 2228-025

Test Engineer H. M. Graham Test Facility W-1

TEST:

Gas Generator

PURPOSE:

Reliability testing of the Gas Generator Assembly.

REMARKS:

All runs smooth and normal.

30-second full thrust firings.

DATA RECORDED ON: Speedomax

At = .2040 in^2 Test No. LD- 23 to LD- 27

TEST NO.	LD- 23		LD- 24		LD- 25		LD- 26		LD- 27	
DURATION sec	30.1		29.7		29.8		29.8		29.5	
ΣDURATION sec	656.5		686.2		716.0		745.8		775.3	
TIME OF DATA	Static	29.6	Static	29.2	Static	29.3	Static	29.3	Static	29.0
LNP psig		286		286		287		285		282
RNP psig		286		286		286		285		283
OGP psig		293		294		293		292		289
FLP psig		410		410		410		410		404
LP psig	535	431	534	434	537	434	535	432	530	429
TP psig	539	489	541	491	538	489	538	489	533	482
ΔP psi		35.2		36.0		35.6		35.9		34.9
W lb/sec		2.29		2.32		2.30		2.32		2.28
LNT °F		1355		1350		1353		1353		1347
RNT °F		1350		1364		1356		1347		1354
OGT °F		1376		1371		1373		1456		1371
FLT °F										
PFT °F										
EXT °F										
BT °F										
Ts_1 °F		1272		1280		1278		1277		1261
Ts_2 °F		1219		1224		1229		1218		1226
Ts_3 °F		1256		1267		1274		1251		1262
C* ft/sec		2980		2941		2972		2931		2958
F lb		281.8		281.8		282.3		280.9		278.5
Isp sec		123.1		121.5		122.7		121.1		122.1
W_{corr} lb/sec		2.29		2.32		2.30		2.32		2.30
F_{corr} lb		281.8		281.8		282.3		280.9		281.4
Pc Abs Corr		301.0		301.0		301.5		300.0		300.5

ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 3

Test Item SN 1	Test No. LD- 28 thru LD- 33	Test Item	SRLD
Date	October 20, 1960	Work Order	2228-025
Test Engineer	F. A. Urbaniak	Test Facility	W-1

TEST:

Gas Generator

PURPOSE:

Reliability testing of the gas generator assembly.

REMARKS:

These runs were for 30 seconds each. There was no noticeable change in performance.

The noise level between the nozzle exits was checked on run LD-28 to be 133.5 db.

DATA RECORDED ON: Speedomax

At = .7040 in^2 Test No. LD- 28 to LD- 33

TEST NO.	LD- 28		LD- 29		LD- 30		LD- 31		LD- 32	
DURATION sec	30.3		30.1		30.1		29.7		29.7	
ΣDURATION sec	805.6		835.7		865.8		895.5		925.2	
TIME OF DATA	Static	29.8	Static	29.6	Static	29.6	Static	29.2	Static	29.2
LNP psig		285		286		285		285		293
RNP psig		287		287		286		286		294
GGP psig		294		294		292		292		301
FLP psig		411		412		410		411		424
LP psig	537	432	540	435	539	435	536	434	540	447
TP psig	539	490	542	500	540	488	541	490	541	506
ΔP psi		36.1		35.9		35.9		35.6		38.0
W lb/sec		2.32		2.32		2.32		2.30		2.37
LNT °F		1347		1348		1344		1338		1346
RNT °F		1356		1347		1350		1344		1341
GGT °F		1364		1352		1351		1351		1354
FLT °F										
PFT °F										
EXT °F										
RT °F										
T_{s1} °F		1303		1244		1242		1250		1251
T_{s2} °F		1238		1223		1225		1231		1226
T_{s3} °F		1275		1254		1254		1242		1246
C* ft/sec		2941		2916		2936		2962		2951
F lb		281.8		282.3		281.4		281.4		288.8
Isp sec		121.5		121.7		121.3		122.3		121.9
W_{corr} lb/sec		2.32		2.31		2.32		2.30		2.32
F_{corr} lb		281.4		281.4		281.4		280.9		282.3
Pc Abs Corr		300.5		300.5		300.5		300.0		301.5

At = .7040 in^2 Test No. LD-28 to LD-33

TEST NO.	LD-33		LD-		LD-		LD-		LD-	
DURATION sec	29.7									
ΣDURATION sec	954.9									
TIME OF DATA	Static	29.2	Static		Static		Static		Static	
LNP psig		286								
RNP psig		287								
OOP psig		293								
FLP psig		413								
LP psig	539	436								
TP psig	542	493								
ΔP psi		35.8								
W lb/sec		2.31								
LNT °F		1340								
RNT °F		1347								
OOT °F		1361								
FLT °F										
PFT °F										
EXT °F										
BT °F										
Ts_1 °F		1238								
Ts_2 °F		1217								
Ts_3 °F		1242								
C* ft/sec		2959								
F lb		2823								
Isp sec		122.2								
W_{corr} lb/sec		2.30								
F_{corr} lb		280.9								
Pc Abs Corr		300.0								

ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 2

Test Item SN 1 Test No. LD- 34 thru LD- 38 Test Item SRLD

Date October 20, 1960 Work Order 2228-025

Test Engineer H. M.Graham Test Facility W-1

TEST:

Gas Generator

PURPOSE:

Reliability testing of the gas generator assembly.

REMARKS:

Setup tank pressure for all runs was 535 psig. No noticeable drop in nozzle pressures occurred during this five (30-sec) run series.

DATA RECORDED ON: Speedomax

At = .7040 in^2 Test No. LD- 34 to LD- 38

TEST NO.	LD- 34		LD- 35		LD- 36		LD- 37		LD- 38	
DURATION sec	29.4		29.9		29.8		30.1		30.0	
ΣDURATION sec	984.3		1014.2		1044.0		1074.1		1104.1	
TIME OF DATA	Static	28.9	Static	29.4	Static	29.3	Static	29.6	Static	29.5
LNP psig		282		283		284		283		284
RNP psig		282		283		285		284		284
OOP psig		290		286		292		291		293
FLP psig		407		408		410		409		409
LP psig	531	429	534	430	535	432	535	431		432
TP psig	532	483	539	490	537	487	536	488		488
ΔP psi		34.7		35.2		35.6		34.7		35.5
W lb/sec		2.28		2.29		2.30		2.28		2.30
LNT °F		1344		1350		1358		1347		1356
RNT °F		1349		1342		1354		1338		1347
OOT °F		1358		1364		1365		1354		1348
FLT °F										
PFT °F										
EXT °F										
BT °F										
Ts_1 °F		1251		1256		1254		1256		- -
Ts_2 °F		1233		1235		1236		1233		- -
Ts_3 °F		1256		1257		1252		1248		- -
C* ft/sec		2953		2950		2952		2968		2947
F lb		278.1		279.0		280.4		279.5		280.0
Isp sec		122.0		121.8		121.9		122.6		121.7
W_{corr} lb/sec		2.29		2.30		2.30		2.28		2.30
F_{corr} lb		279.5		280.0		280.4		280.0		280.4
Pc Abs Corr		298.5		299.0		299.5		299.0		299.5

A_t = .7040 in^2 Test No. LD- 34 to LD- 38

TEST NO.		LD- 34		LD- 35		LD- 36		LD- 37		LD- 38	
DURATION	sec	29.4		29.9		29.8		30.1		30.0	
ΣDURATION	sec	984.3		1014.2		1044.0		1074.1		1104.1	
TIME OF DATA		Static	28.9	Static	29.4	Static	29.3	Static	29.6	Static	29.5
LNP	psig		282		283		284		283		284
RNP	psig		282		283		285		284		284
OOP	psig		290		286		292		291		293
FLP	psig		407		408		410		409		409
LP	psig	531	429	534	430	535	432	535	431		432
TP	psig	532	483	539	490	537	487	536	488		488
ΔP	psi		34.7		35.2		35.6		34.7		35.5
W	lb/sec		2.28		2.29		2.30		2.28		2.30
LNT	°F		1344		1350		1358		1347		1356
RNT	°F		1349		1342		1354		1338		1347
OOT	°F		1358		1364		1365		1354		1348
FLT	°F										
PFT	°F										
EXT	°F										
BT	°F										
T_{s1}	°F		1251		1256		1254		1256		--
T_{s2}	°F		1233		1235		1236		1233		--
T_{s3}	°F		1256		1257		1252		1248		--
C*	ft/sec		2953		2950		2952		2968		2947
F	lb		278.1		279.0		280.4		279.5		280.0
Isp	sec		122.0		121.8		121.9		122.6		121.7
W_{corr}	lb/sec		2.29		2.30		2.30		2.28		2.30
F_{corr}	lb		279.5		280.0		280.4		280.0		280.4
Pc Abs Corr			298.5		299.0		299.5		299.0		299.5

ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 2

Test Item SN	1	Test No.	LD- 39 thru LD- 43	Test Item	SRLD
Date	October 21, 1960			Work Order	2228-025
Test Engineer	F. A. Urbaniak, 1st shift			Test Facility	W-1

TEST:

Gas generator

PURPOSE:

Reliability testing of the gas generator assembly.

REMARKS:

No noticeable drop in nozzle pressure was recorded in these runs.

Left nozzle temperature did not record during runs LD-40 and 41. (30-second duration firings).

DATA RECORDED ON: Speedomax

At = .2040 in²　　Test No. LD- 39 to LD- 43

TEST NO.	LD- 39		LD- 40		LD- 41		LD- 42		LD- 43	
DURATION sec	29.8		30.4		30.0		29.9		29.8	
ΣDURATION sec	1133.9		1164.3		1194.3		1224.2		1254.0	
TIME OF DATA	Static	29.3	Static	29.9	Static	29.5	Static	29.4	Static	29.3
LNP psig		285		285		288		285		286
RNP psig		284		284		288		285		285
GGP psig		292		291		295		292		291
FLP psig		411		409		415		411		410
LP psig	533	430	533	432	537	436	534	432	532	432
TP psig	540	490	539	490	542	494	539	490	538	488
ΔP psi		35.5		35.5		36.3		35.5		35.4
W lb/sec		2.30		2.30		2.33		2.30		2.29
LNT °F		1352		--		--		--		--
RNT °F		1350		1360		1352		1374		1355
GGT °F		1359		1347		1344		1382		1360
FLT °F										
PFT °F										
EXT °F										
BT °F										
Ts_1 °F		1254		1206		1247		1248		1268
Ts_2 °F		1256		1221		1221		1167		1206
Ts_3 °F		1252		1241		1238		1261		1247
C* ft/sec		2952		2952		2948		2957		2975
F lb		280.4		280.4		283.7		280.9		281.4
Isp sec		121.9		121.9		121.8		122.1		122.9
W_{corr} lb/sec		2.30		2.30		2.31		2.30		2.29
F_{corr} lb		280.0		280.9		281.4		280.4		281.4
Pc Abs Corr		299.0		300.0		300.5		299.5		300.5

ROCKET LABORATORY PRELIMINARY TEST REPORT

Test Item SN 1 Test No. LD- 44 thru LD- 47 Test Item SRLD

Date October 21, 1960, 2nd shift Work Order 2228-025

Test Engineer H. M. Graham Test Facility W-1

TEST:

Gas Generator

PURPOSE:

Reliability testing of the gas generator assembly.

REMARKS:

No noticeable drop in nozzle pressure was recorded in these runs (30-second duration firings).

DATA RECORDED ON: Speedomax

At = .7040 in^2 Test No. LD- 44 to LD- 47

TEST NO.	LD- 44		LD- 45		LD- 46		LD- 47		LD-	
DURATION sec	30.0		29.7		29.7		30.5			
ΣDURATION sec	1284.0		1313.7		343.4		1373.9			
TIME OF DATA	Static	29.5	Static	29.2	Static	29.2	Static	30.0	Static	
LNP psig		284		286		286		287		
RNP psig		283		285		286		286		
GGP psig		291		293		292		294		
FLP psig		410		411		412		412		
LP psig	532	433	535	434	533	433	538	437		
TP psig	538	489	542	491	538	489	543	494		
ΔP psi		35.4		35.6		35.5		36.0		
W lb/sec		2.29		2.30		2.30		2.32		
LNT °F		-		-		-		-		
RNT °F		1362		1369		1364		1358		
GGT °F		1330		1350		1364		1361		
FLT °F										
PFT °F										
EXT °F										
BT °F										
T_{s1} °F		1268		1267		1271		1256		
T_{s2} °F		1217		1215		1216		1226		
T_{s3} °F		1240		1242		1244		1246		
C* ft/sec		2955		2962		2967		2946		
F lb		279.5		281.4		281.0		282.3		
Isp sec		122.1		122.3		122.5		121.7		
W_{corr} lb/sec		2.29		2.30		2.29		2.31		
F_{corr} lb		279.5		281.4		280.9		281.4		
Pc Abs Corr		298.5		300.0		300.0		300.5		

ROCKET LABORATORY PRELIMINARY TEST REPORT

Test Item SN 1 Test No. LD- 48 thru LD- Test Item SRLD

Date October 27, 1960, 1st Shift Work Order 2228-025

Test Engineer L. Goldschlag Test Facility W-1

TEST:

Gas Generator Assembly.

PURPOSE:

Reliability testing of the gas generator assembly and determination of torque required to move the swivel nozzle assembly.

REMARKS:

Prior to this test the swivel nozzles and manual remote actuating rod were installed on the test assembly. Thermocouples for measuring the propellant feed temperature and for measuring the temperature of the lift ring mount bracket were also installed.

No noticeable drop in nozzle pressure was recorded in this run. Left nozzle temperature did not record.

Tank pressure was increased in several steps.

DATA RECORDED ON: Speedomax

At = .7040 in^2 Test No. LD-48 to LD-

TEST NO.	LD-48		LD-48		LD-		LD-		LD-	
DURATION sec	47.0									
ΣDURATION sec			1420.9							
TIME OF DATA	Static	10.0	20.0	46.5	Static		Static		Static	
LNP psig		176	248	320						
RNP psig		177	248	321						
CCP psig		183	257	331						
FLP psig		250	354	466						
LP psig	298	259	370	492						
TP psig	304	287	416	566						
ΔP psi		15.6	28.7	46.7						
W lb/sec		1.56	2.09	2.62						
LNT °F		Lost	1131	1153						
RNT °F	Open	Thermocouple								
CCT °F		1406	1408	1414						
FLT °F										
PFT °F	63	56	56	59						
EXT °F										
BT °F	64	68	77	90						
T_{s1} °F										
T_{s2} °F										
T_{s3} °F										
C* ft/sec		2783	2853	2903						
F lb		179.3	246.2	314.1						
Isp sec		114.9	117.8	119.9						
W_{corr} lb/sec		2.21	2.31	2.40						
F_{corr} lb		254.2	272.5	287.9						
Pc Abs Corr		271.5	291.0	307.5						

ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 2

Test Item SN 1 Test No. LD- 49 thru LD- Test Item SRLD

Date October 27, 1960 Work Order 2228-025

Test Engineer L. P. Sileo, 2nd Shift Test Facility W-1

TEST:

Gas Generator

PURPOSE:

Reliability testing of the gas generator assembly.

REMARKS:

No noticeable drop in nozzle pressure was recorded in this run (30-second duration firing).

DATA RECORDED ON: Speedomax

At = .7040 in^2 Test No. LD- 49 to LD-

TEST NO.	LD- 49		LD-		LD-		LD-		LD-	
DURATION sec	29.9									
ΣDURATION sec	1450.8									
TIME OF DATA	Static	29.4	Static		Static		Static		Static	
LNP psig		285								
RNP psig		285								
GOP psig		293								
FLP psig		410								
LP psig	531	429								
TP psig	540	488								
ΔP psi		35.8								
W lb/sec		2.31								
LNT °F		1346								
RNT °F	Open	Thermocouple								
GGT °F		1394								
FLT °F										
PFT °F	54	53								
EXT °F										
BT °F	55	77								
Ts_1 °F										
Ts_2 °F										
Ts_3 °F										
C* ft/sec		2944								
F lb		280.9								
Isp sec		121.6								
W_{corr} lb/sec		2.31								
F_{corr} lb		280.9								
Pc Abs Corr		300.0								

ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 1

Test Item SN	1	Test No. LD- 50 thru LD- 53		Test Item	SRLD
Date	October 28, 1960			Work Order	2228-025
Test Engineer	L. Goldschlag, 1st Shift			Test Facility	W-1

TEST:

Gas Generator Assembly

PURPOSE:

Reliability testing of the gas generator assembly.

REMARKS:

No noticeable drop in nozzle pressure was recorded in these runs (30-second firings).

DATA RECORDED ON: Speedomax

At = .7040 in²   Test No. LD- 50 to LD- 53

TEST NO.	LD- 50		LD- 51		LD- 52		LD- 53		LD-	
DURATION sec	30.4		29.9		30.0		30.0			
ΣDURATION sec	1481.2		1511.1		1541.1		1571.1			
TIME OF DATA	Static	29.9	Static	29.4	Static	29.5	Static	29.5	Static	
LNP psig		286		282		285		283		
RNP psig		287		283		285		284		
GOP psig		294		291		292		292		
FLP psig		415		408		411		412		
LP psig	537	435	529	431	531	432	530	430		
TP psig	543	492	536	488	540	492	490	537		
ΔP psi		35.7		35.1		35.6		35.6		
W lb/sec		2.30		2.28		2.30		2.30		
LNT °F		1336		1330		1362		1338		
RNT °F	No Record			1338		1276		1340		
GGT °F		1361		1374		1343		1367		
FLT °F										
PFT °F	54	46	67	48	70	48	66	51		
EXT °F										
BT °F	53	74	63	86	65	88	63	86		
Ts_1 °F										
Ts_2 °F										
Ts_3 °F										
C* ft/sec		2972		2958		2957		2942		
F lb		282.3		278.5		280.9		279.5		
Isp sec		122.7		122.1		122.1		121.5		
W_{corr} lb/sec		2.28		2.29		2.30		2.29		
F_{corr} lb		280.0		279.5		280.4		278.5		
Pc Abs Corr		299.0		298.5		299.5		297.5		

ROCKET LABORATORY PRELIMINARY TEST REPORT

Test Item SN 1 Test No. LD- 54 thru LD- 61 Test Item SRLD

Date October 28, 1960 Work Order 2228-025

Test Engineer L. P. Silso, 2nd Shift Test Facility W-1

TEST:

Gas Generator Assembly

PURPOSE:

Reliability testing of the gas generator assembly.

REMARKS:

No noticeable drop in nozzle pressure was recorded (30-second duration firings).

DATA RECORDED ON: Speedomax

At = .7040 in^2 Test No. LD- 54 to LD- 61

TEST NO.	LD- 54		LD- 55		LD- 56		LD- 57		LD- 58	
DURATION sec	29.5		29.9		30.8		30.1		29.7	
ΣDURATION sec	1600.6		1630.5		1661.3		1691.4		1721.1	
TIME OF DATA	Static	29.0	Static	29.4	Static	30.3	Static	29.6	Static	29.2
LNP psig		286		285		283		284		284
RNP psig		287		286		284		284		286
OGP psig		293		295		291		292		292
FLP psig		414		413		409		411		412
LP psig	538	437	541	438	532	433	525	435	538	434
TP psig	541	494	543	495	536	489	539	492	541	489
ΔP psi		36.1		36.3		35.1		36.0		36.1
W lb/sec		2.32		2.33		2.28		2.32		2.32
LNT °F		1348		1353		1354		1352		1355
RNT °F		1354		1350		1332		1338		1344
OGT °F		1379		1369		1367		1372		1356
FLT °F										
PFT °F	59	56	67	55	72	54	66	53	57	52
EXT °F										
BT °F										
T_{s1} °F										
T_{s2} °F										
T_{s3} °F										
C* ft/sec		2946		2924		2968		2922		2936
F lb		282.3		281.4		279.5		280.0		293.6
Isp sec		121.7		120.7		122.6		120.7		121.3
W_{corr} lb/sec		2.30		2.32		2.28		2.32		2.31
F_{corr} lb		280.4		280.0		280.0		279.5		280.0
Pc Abs Corr		299.5		299.0		299.0		298.5		299.0

At = .7040 in^2 Test No. LD- 54 to LD- 61

TEST NO.	LD- 59		LD- 60		LD- 61		LD-		LD-	
DURATION sec	30.0		29.8		41.4					
ΣDURATION sec	1761.1		1780.9		1822.3					
TIME OF DATA	Static	29.5	Static	29.3	Static	30.0	Static	40.9	Static	
LNP psig		285		283		284		284		
RNP psig		284		284		285		285		
GGP psig		293		291		291		292		
FLP psig		411		410		413		413		
LP psig	538	435	536	433	535	436		436		
TP psig	540	490	538	490	538	492		492		
ΔP psi		36.2		35.7		36.2		36.2		
W lb/sec		2.33		2.30		2.33		2.33		
LNT °F		1340		1348		1330		1332		
RNT °F		1318		1344		1344		1347		
GGT °F		1362		1371		1362		1362		
FLT °F										
PFT °F	66	52	71	50	63	50		50		
EXT °F										
BT °F										
T_{s1} °F										
T_{s2} °F										
T_{s3} °F										
C* ft/sec		2974		2942		2914		2914		
F lb		280.4		279.5		280.4		280.4		
Isp sec		120.4		121.5		120.3		120.3		
W_{corr} lb/sec		2.33		2.30		2.32		2.32		
F_{corr} lb		280.0		279.5		279.0		279.0		
Pc Abs Corr		299.0		298.5		298.0		298.0		

ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 2

Test Item SN 1 Test No. LD- 62 thru LD- 65 Test Item SRLD

Date October 31, 1960 Work Order 2228-025

Test Engineer L. Goldschlag, 1st Shift Test Facility W-1

TEST:

Gas Generator Assembly.

PURPOSE:

Reliability testing of the gas generator assembly.

REMARKS:

No noticeable drop in nozzle pressure was recorded (30-second duration firings).

DATA RECORDED ON: Speedomax

CELL W-1

At = .7040 in^2 Test No. LD-62 to LD-65

TEST NO.	LD-62		LD-63		LD-64		LD-65		LD-	
DURATION sec	29.6		29.8		30.5		30.4			
ΣDURATION sec	1851.9		1881.7		1912.2		1942.6			
TIME OF DATA	Static	29.1	Static	29.3	Static	30.1	Static	29.9	Static	
LNP psig		284		284		286		287		
RNP psig		284		282		287		286		
OGP psig		291		289		298		292		
FLP psig		412		410		413		413		
LP psig	538	437	533	435	543	442	540	441		
TP psig	538	493	532	486	539	492	540	493		
ΔP psi		35.6		35.3		36.5		36.4		
W lb/sec		2.30		2.29		2.34		2.33		
LNT °F		1384		1349		1362		1359		
RNT °F		1334		1334		1337		1332		
OGT °F		1377		1356		1356		1376		
FLT °F										
PFT °F	58	49	69	52	71	53	64	54		
EXT °F	56	681	58	596	64	584	59	563		
BT °F										
Ts_1 °F										
Ts_2 °F										
Ts_3 °F										
C* ft/sec		2947		2950		2921		2933		
F lb		280.0		279.0		282.3		282.3		
Isp sec		121.7		121.8		120.6		121.2		
W_{corr} lb/sec		2.29		2.29		2.33		2.32		
F_{corr} lb		279.0		279.0		280.9		280.9		
Pc Abs Corr		298.0		298.0		300.0		300.0		

ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 3

Test Item SN 1 Test No. LD-66 thru LD-72 Test Item SRLD

Date October 31, 1960 Work Order 2228-025

Test Engineer L. Sileo, 2nd Shift Test Facility W-1

TEST:

Gas Generator Assembly.

PURPOSE:

Reliability testing of the gas generator assembly.

REMARKS:

No noticeable drop in nozzle pressure was recorded (30-second duration firings).

DATA RECORDED ON: Speedomax

At = .7040 in^2 Test No. LD- 66 to LD- 72

TEST NO.	LD- 66		LD- 67		LD- 68		LD- 69		LD- 70	
DURATION sec	29.6		31.7		31.6		31.2		30.8	
ΣDURATION sec	1972.2		2003.9		2035.5		2066.7		2097.5	
TIME OF DATA	Static	29.1	Static	31.2	Static	31.5	Static	30.7	Static	30.3
LNP psig		287		285		287		286		286
RNP psig		287		283		286		287		285
GOP psig		292		289		292		292		292
FLP psig		416		410		414		413		413
LP psig	540	440	530	430	534	435	536	436	535	437
TP psig	544	495	537	490	538	490	538	491	540	491
ΔP psi		35.7		35.4		36.0		36.0		35.8
W lb/sec		2.30		2.29		2.32		2.32		2.31
LNT °F		1346		1346		1343		1347		1350
RNT °F		1331		1332		1331		1320		1326
OGT °F	Unreliable			1382		1379		1382		1371
FLT °F										
PFT °F	59	55	69	55	72	54	Unreliable		68	53
EXT °F										
BT °F										
Ts_1 °F										
Ts_2 °F										
Ts_3 °F										
C* ft/sec		2977		2960		2946		2946		2949
F lb		282.7		280.0		282.3		282.3		281.4
Isp sec		122.9		122.3		121.7		121.7		121.0
W_{corr} lb/sec		2.28		2.29		2.30		2.31		2.30
F_{corr} lb		280.0		280.0		280.4		280.9		280.0
Pc Abs Corr		299.0		299.0		299.5		300.0		299.0

At = .7040 in^2 Test No. LD- 66 to LD- 72

TEST NO.	LD- 71		LD- 72		LD-		LD-		LD-	
DURATION sec	30.6		30.3							
ΣDURATION sec	2128.1		2158.4							
TIME OF DATA	Static	30.1	Static	29.8	Static		Static		Static	
LNP psig		287		289						
RNP psig		288		289						
GGP psig		286		294						
FLP psig		416		417						
LP psig	540	441	545	443						
TP psig	543	495	545	495						
ΔP psi		36.2		36.4						
W lb/sec		2.33		2.33						
LNT °F		1350		1348						
RNT °F		1331		1330						
GGT °F		1361		1366						
FLT °F										
PFT °F	58	49	68	49						
EXT °F										
BT °F										
Ts_1 °F										
Ts_2 °F										
Ts_3 °F										
C* ft/sec		2943		2958						
F lb		283.2		284.6						
Isp sec		121.6		122.2						
W_{corr} lb/sec		2.31		2.30						
F_{corr} lb		280.4		281.4						
Pc Abs Corr		299.5		300.5						

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ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 2

Test Item SN 1 Test No. LD- 73 thru LD- 77 Test Item SRLD

Date November 1, 1960 Work Order 2228-025

Test Engineer L. Goldschlag, 1st Shift Test Facility W-1

TEST:

Gas Generator Assembly

PURPOSE:

Reliability testing of the gas generator assembly.

REMARKS:

No noticeable drop in nozzle pressure was recorded (30-second duration firings).

DATA RECORDED ON: Speedomax

CELL W-1

At = .7040 in^2 Test No. LD- 73 to LD- 77

TEST NO.	LD- 73		LD- 74		LD- 75		LD- 76		LD- 77	
DURATION sec	30.3		30.0		29.7		30.2		30.5	
ΣDURATION sec	2188.7		2218.7		2248.4		2278.6		2309.1	
TIME OF DATA	Static	29.8	Static	29.5	Static	29.2	Static	29.7	Static	30.0
LNP psig		288		288		288		288		286
RNP psig		288		287		287		288		285
GGP psig		292		292		292		293		290
FLP psig		414		414		414		416		412
LP psig	534	424	538	438	539	439	536	439	Unreli	able
TP psig	539	494	539	496	549	493	538	492	539	492
ΔP psi		36.3		36.2		36.5		36.4		35.8
W lb/sec		2.33		2.33		2.34		2.33		2.31
LNT °F		1330		1340		1343		1341		1343
RNT °F		1340		1305		1337		1293		1353
GGT °F		1326		1369		1364		1379		1395
FLT °F										
PFT °F	52	52	58	52	60	53	55	53	52	52
EXT °F	-	-	53	472	53	462	51	461	52	392
BT °F										
Ts_1 °F										
Ts_2 °F										
Ts_3 °F										
C* ft/sec		2948		2943		2931		2948		2949
F lb		283.7		283.2		282.3		283.7		281.4
Isp sec		121.8		121.6		121.0		121.8		121.8
W_{corr} lb/sec		2.31		2.31		2.32		2.31		2.30
F_{corr} lb		281.8		281.4		281.4		280.9		280.4
Pc Abs Corr		301.0		300.5		300.5		300.0		299.5

ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 3

Test Item SN 1 Test No. LD- 78 thru LD- 83 Test Item SRLD

Date November 1, 1960 Work Order 2228-025

Test Engineer L. P. Sileo Test Facility W-1

TEST:

Gas Generator Assembly

PURPOSE:

Reliability testing of the gas generator assembly.

REMARKS:

No noticeable drop in nozzle pressure was recorded (30-second duration firings).

DATA RECORDED ON: Speedomax

A_t = .2040 in^2 Test No. LD- 78 to LD- 83

TEST NO.	LD- 78		LD- 79		LD- 80		LD- 81		LD- 82	
DURATION sec	30.9		30.5		31.0		30.5		30.6	
ΣDURATION sec	2340.0		2370.5		2401.5		2432.0		2462.6	
TIME OF DATA	Static	30.4	Static	30.0	Static	30.5	Static	30.0	Static	30.1
LNP psig		287		289		288		288		288
RNP psig		286		288		288		288		288
GGP psig		292		294		294		294		293
FLP psig		412		413		414		414		417
LP psig	533	433	538	436	540	437	537	437	536	437
TP psig	538	490	542	496	543	494	541	495	540	494
ΔP psi		36.2		36.6		36.5		36.9		36.0
W lb/sec		2.33		2.34		2.34		2.35		2.32
LNT °F		1353		1352		1356		1350		1346
RNT °F		1352		1337		1338		1328		1328
GGT °F		1393		1375		1374		1380		1362
FLT °F										
PFT °F	57	51	61	53	70	53	58	53	52	51
EXT °F										
BT °F										
T_{s1} °F										
T_{s2} °F										
T_{s3} °F										
C* ft/sec		2933		2940		2935		2923		2961
F lb		282.3		284.2		283.7		283.7		283.7
Isp sec		121.2		121.4		121.2		120.7		122.3
W_{corr} lb/sec		2.32		2.33		2.32		2.33		2.29
F_{corr} lb		282.3		284.2		283.7		281.8		280.4
Pc Abs Corr		300.5		302.0		301.0		301.0		299.5

CELL W-1 Sheet 3 of 3

At = .7040 in^2 Test No. LD- 78 to LD- 83

TEST NO.	LD- 83		LD-		LD-		LD-		LD-	
DURATION sec	31.6									
ΣDURATION sec	2494.2									
TIME OF DATA	Static	31.1	Static		Static		Static		Static	
LNP psig		286								
RNP psig		286								
GGP psig		292								
FLP psig		415								
LP psig	537	438								
TP psig	539	493								
ΔP psi		36.3								
W lb/sec		2.31								
LNT °F		1358								
RNT °F		1318								
GGT °F		1364								
FLT °F										
PFT °F	64	49								
EXT °F										
BT °F										
Ts_1 °F										
Ts_2 °F										
Ts_3 °F										
C* ft/sec		2928								
F lb		281.8								
Isp sec		121.0								
W_{corr} lb/sec		2.31								
F_{corr} lb		279.5								
Pc Abs Corr		298.5								

ROCKET LABORATORY PRELIMINARY TEST REPORT

Test Item SN	1	Test No. LD- 84 thru LD-	Test Item SRLD
Date	November 2, 1960		Work Order 2228-025
Test Engineer	L. Goldschlag, 1st Shift		Test Facility W-1

TEST:

Gas Generator Assembly.

PURPOSE:

Reliability testing of the gas generator assembly and observing heat transfer characteristics of the liquid between the gas generator and the throttle valve.

REMARKS:

The propellant feed temperature was recorded between each burst and after the last burst for about 15 minutes. The line was not purged after each burst.

Three ten-second full thrust firings with 3 minutes between the start of each burst.

DATA RECORDED ON: Speedomax

At = .7040 in^2 Test No. LD- 84* to LD- (3-10 Second Bursts)*

TEST NO.	LD- 84		LD- 84		LD- 84		LD-		LD-	
DURATION sec	10.0		9.8		10.5					
ΣDURATION sec					2524.5					
TIME OF DATA	Static	9.5	Static	9.3	Static	10.0	Static		Static	
	1st Burst		2nd Burst		3rd Burst					
LNP psig		286		288		289				
RNP psig		286		288		288				
GGP psig		291		293		294				
FLP psig		415		417		419				
LP psig		Unreliable								
TP psig	543	495	547	502	550	503				
ΔP psi		36.2		36.6		36.9				
W lb/sec		2.33		2.34		2.35				
LNT °F		1298		1335		1341				
RNT °F		1285		1304		1309				
GGT °F	OSN	1370	778	1371	812	1286				
FLT °F										
PFT °F	51	48	54	49	57	49				
EXT °F										
BT °F										
T_{s1} °F										
T_{s2} °F										
T_{s3} °F										
C* ft/sec		2928		2935		2928				
F lb		281.8		283.7		284.2				
Isp sec		121.0		121.2		120.9				
W_{corr} lb/sec		2.31		2.31		2.32				
F_{corr} lb		279.5		280.4		280.0				
Pc Abs Corr		298.5		299.5		299.0				

ROCKET LABORATORY PRELIMINARY TEST REPORT

Sheet 1 of 2

Test Item SN 1 Test No. LD- 85 thru LD- 88 Test Item SRLD

Date November 2, 1960 Work Order 2228-025

Test Engineer L. Goldschlag, 1st Shift Test Facility W-1

TEST:

Gas Generator Assembly.

PURPOSE:

Reliability testing the gas generator assembly.

REMARKS:

Run LD-85 Recorded propellant feed temperature for about 25 minutes after shutdown.

Run LD-88 Ran until tank was emptied of H_2O_2 , about 55 seconds

No noticeable drop in nozzle pressure was recorded in these runs.

DATA RECORDED ON: Speedomax

At = .7040 in^2 Test No. LD- 85 to LD- 88

TEST NO.	LD- 85		LD- 86		LD- 87		LD- 88		LD- 88	
DURATION sec	29.4		29.9		30.3		46.0			
ΣDURATION sec	2553.9		2583.8		2614.1				2660.1	
TIME OF DATA	Static	28.9	Static	29.4	Static	29.8	Static	30.0	Static	45.5
LNP psig		287		285		286		286		286
RNP psig		288		284		285		286		286
OGP psig		293		290		290		290		291
FLP psig		415		411		412		412		412
LP psig	536	436	534	434	537	434	535	434		434
TP psig	544	495	536	490	540	490	539	492		492
ΔP psi		36.4		35.7		36.2		36.3		36.1
W lb/sec		2.33		2.30		2.33		2.33		2.32
LNT °F		1356		1354		1358		1358		1361
RNT °F		1326		1326		1311		1312		1315
OGT °F		1356		1338		1328		1328		1328
FLT °F										
PFT °F	54	51	48	49	56	48	55	48		48
EXT °F										
BT °F										
T_{s1} °F										
T_{s2} °F										
T_{s3} °F										
C* ft/sec		2943		2952		2924		2928		2941
F lb		283.2		280.4		281.5		281.8		281.8
Isp sec		121.6		121.9		120.8		121.0		121.5
W_{corr} lb/sec		2.31		2.30		2.32		2.32		2.31
F_{corr} lb		280.9		280.0		280.4		280.9		280.9
Pc Abs Corr		300.0		299.0		299.5		300.0		300.0

AD________________ Accession No.________

Bell Aerosystems Company
Division of Bell Aerospace Corporation
Buffalo 5, New York, SMALL ROCKET LIFT DEVICE - PHASE I DESIGN, FABRICATION, AND STATIC TESTING. W.F. MOORE, J. KROLL, J. BURGESS, S. CZARNECKI.

Report No. TREC TR 61-45, March 1961 145pp. (Contract DA44-177-TC-642) USATRECOM Proj 9R38-11-009-14, ST__________ Unclassified Report.

The design of a manned small rocket lift device is described. A stability and control analysis is presented with recommendations. Component development is described. Test

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1. Manned Rocket Lift Device.

2. Contract No. DA44-177-TC-642

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data including reliability determinations on component and system levels is presented. Results indicate the system is suitable for manned flight testing. Recommendations are made to proceed immediately with hot system firings and manned flight testing.

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